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Water Supply for Counterinsurgency Operations in Northeast Thailand

by
David B. Dean
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RAC

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McLEAN, VIRGINIA

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FOREWORD

Perhaps no commodity so significantly influences human occupation and progress throughout the world as does water. The development of adequate supplies is a continuous problem just for ordinary domestic consumption, but beyond this the requirements for military operations impose special burdens. The problems are especially acute in areas of periodic floods and drought such as Northeast Thailand. Although this paper is concerned primarily with water supply for counterinsurgency forces operating in Northeast Thailand, these problems are not fundamentally separable from those of the indigenous peoples. Therefore both the civilian and military aspects of water-supply development are addressed here.

The data presented in this report are the result of investigations conducted in Thailand during a period of approximately 90 days from mid-December 1965 to mid-March 1966. Research was directed primarily toward an inventory of the status of knowledge concerning the physical environment of Northeast Thailand including hydrology and water resources; a survey of existing water-development and management programs; and the study of the Royal Thai Army (RTA) with particular reference to Engineer organization, responsibilities, and equipment for counterinsurgency operations. A limited but significant amount of direct field observation was possible in the time allotted for the project.

The paper includes, first, a discussion of the logistics of water supply in the context of RTA and paramilitary operations in Northeast Thailand, an inventory of existing water resources, and an analysis of water-supply considerations through projected military deployments based on a scenario of escalating communist insurgent effort; second, a series of three appendixes treating the physical environment, hydrology, and water resources of the region in detail, as well as a presentation of general background information plus the scenario itself; and third, a technical glossary followed by the references and an annotated bibliography of the subjects treated in the paper. Such organization is believed to afford flexibility in the ultimate uses of the paper.

No attempt is made in this paper to address ancillary problems such as troop physiological water requirements under various conditions of energy expenditure, food and salt intake, perspiration loss, ambient temperature and humidity, etc, or other problems such as road networks, off-road routes for water-transport vehicles during various seasons of the year, the design or modification of such vehicles, and so on. Such problems are appropriate for separate study in order that they may be given full consideration.

George A. Martinez
Head, Unconventional Warfare Department

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The writers wish to express their great appreciation to the many persons and agencies who cooperated in various ways to make available the information on which this investigation depends. In particular the help of the US Operations Mission (USOM), Thailand; the Joint US Military Advisory Group, Thailand; the US Army, Pacific, G4; the Royal Thai Government (RTG) Departments of Mineral Resources, Irrigation, and Meteorology; the US Geological Survey in Washington, D. C.; and the RTA is acknowledged. The project is particularly indebted to Mr. Phongphan Na Chiengmai and Mr. Chareon Phiancharoen of the RTG Department of Mineral Resources, Ground Water Division; Mr. William A. McQuary of the USOM Public Health Division; Dr. F. R. Moormann of the Food and Agricultural Organization and RTG Department of Land Development Soil Survey Section; and Dr. Thomas Southwick, Director of the World Meteorological Organization in Bangkok.

The original manuscript was read critically by Dr. Philip E. LaMoreaux, State Geologist of Alabama and a pioneer investigator of the hydrology of Northeast Thailand, whose comments and criticism are gratefully acknowledged. MAJ Warren B. Stevens, USA (Ret), the writers' colleague at RAC, also generously contributed suggestions on the organization and presentation of certain information. Although each of the above-mentioned persons probably agrees in general with various substantive portions of this study, none have been asked nor have had the opportunity to endorse this final manuscript in detail; it is therefore the exclusive responsibility of the writers.

Finally the project was assisted in many ways by Mr. Robert A. Slaybecker and Mr. Raymond E. Bailey, who performed many liaison tasks, procured refence information, and prepared graphic materials for publication; their help is noted with appreciation.

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Problem

To examine the status of water-resources investigations in Northeast Thailand, with particular reference to problems of civil and military water supply, so as to suggest ways and means of improving existing water supply and forestalling potential water shortages in counterinsurgency operations.

Facts

With about 65,000 sq mi and a population of roughly 10 million, Northeast Thailand is about one-third of the entire country. The Northeast is undeveloped in many ways, partly because it is poor in agricultural and mineral resources. Potable water is in short supply in many areas, as are water-distribution systems. Rice is the principal crop with some accessory farming and logging. Farm households make up 87 percent of the total, suggesting to some extent the problem of water supply for thousands of villages. The people live in relative poverty and are generally in poor health. Enteric disease rates are high, partly from bad water. Some salt-contaminated water is consumed because in some localities people have found nothing else.

Communist subversion is apparently increasing in the Northeast, and an insurgency culminating in military combat seems to be heralded by increasing agitation, terrorism, and infiltration of subversives from outside the country. The problem of developing a better water supply for the civilian population is coupled with that of ensuring that sufficient water would be available to counterinsurgency forces if field operations were to be undertaken. Economic factors and military factors both enter into any planning of water-supply development in the Northeast.

Although the insurgency (from press reports of incidents) appears to be increasing in intensity, the water-supply-development situation seems slowly to be improving. Approximately 1600 wells have been drilled in the past 10 years; however, not all of them are productive. Water-resources studies are under way by the Royal Thai Government (RTG) and, further, a number of Thai, US, and UN agencies are concerned with both ground-water development and surface-water management in terms of irrigation and flood control.

From the standpoint of the Royal Thai Army (RTA), current forces in Northeast Thailand (the RTA Second Army area) are in garrison where dependable permanent water supplies have been developed. But if deployment

were necessary, either at the present level of intensity of insurgency (Phase 1) or at rising levels such as Phase II or Phase III, increasing numbers of army units would be forced to solve their individual problems of water supply in field operations.

Discussion

The overall water-supply situation is approached in two ways in the present study. One aims at investigation of the overall water-resources situation based on evaluation of the results of research in progress by a number of scientists in a variety of agencies. Any attempt to determine the quantity and quality of water obtainable either at the surface or from underground necessitates investigation of the environmental system that produces water resources, sometimes called the regional hydrologic "cycle," which is actually a large open system. Its two principal independent variables are the regional physical geology and the general system of atmospheric circulation, which in turn affect a series of interacting semi-independent variables including temperature, humidity, topography, precipitation, vegetation, and soils. The latter two are deeply involved with the ambient processes of surface-water runoff, infiltration, evaporation, transpiration, and residual concentration of water. Finally the two completely dependent variables, surface-water resources and ground-water resources, are in equilibrium with the system and very sensitively adjusted to each other. In summary the regional geologic situation over the short term is the invariant framework within which hydrology functions as a set of dependent subsystems, defining the ground-water and surface-water provinces, or separate systems of accumulation and discharge. Details of these relations in terms of their influence on the occurrence of water resources, indications of preferred methods of exploitation, and any incidental hydrologic benefits or potential payoffs are presented.

The second approach involves the preparation of "scenarios" in which conjectural events, considered to have a reasonable probability of occurrence, are projected in hypothetical sequence to illustrate the nature of real planning problems and constraints that might arise through three possible successive stages of insurgency in Northeast Thailand. Potential responsive counterinsurgency activity is suggested, including deployments of the RTA. This establishes a framework of plausible relations that serves to set forth the problems of operations and logistics.

The two approaches are combined (Fig. 1) to show the military demand for water vs the availability of water in various projected situations. The examination of these comparisons furnishes the principal base on which this study is built and from which its conclusions are drawn.

A critical military tradeoff exists between (a) the natural availability of water in the combat theater and (b) the total cost of bringing enough water to

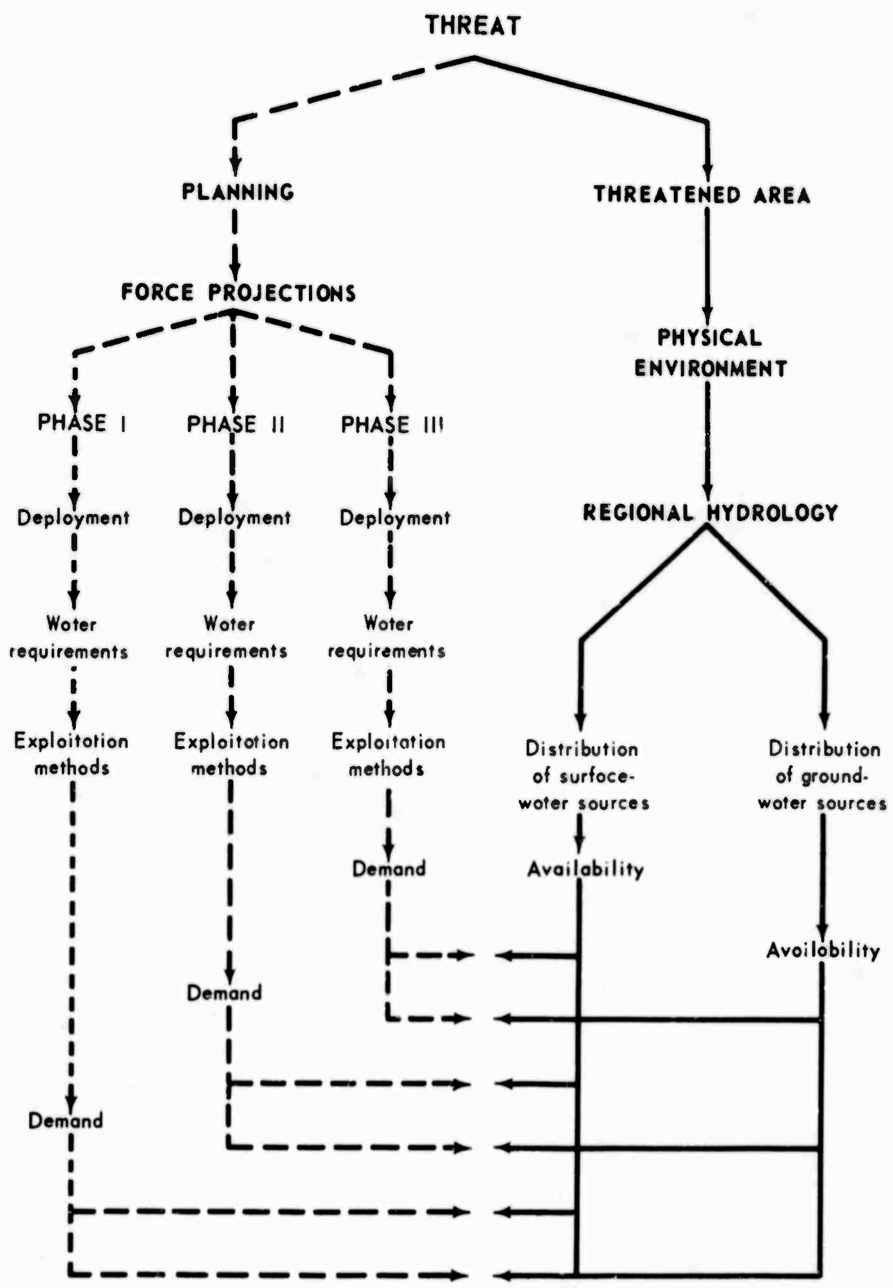


Fig. 1—Method of Generating Probable Demand/Availability Relations for Analysis of Water Supply in Northeast Thailand

satisfy the entire requirement from some significant distance. In many or most theaters the probability is fairly high that enough water will be available most of the time, but this is by no means a certainty, nor will it be true in every place. Measured against this is the certainty of rather high absolute military cost of bringing water all the way into the theater, including transport, distribution, and the vulnerability of such a system to destruction or sabotage with consequent effect on tactical viability. In general it has been feasible to rely on local water availability, but as operations become more efficient and the necessity increases of avoiding foreseeable failures at any reasonable cost, a mounting premium is paid to ensure the successful determination of water resources available not only within the theater but as close as is practicable to the battlefield. Although this is ordinarily an engineer-intelligence function, the RTA has no engineer-intelligence sections or functions for assessing the potential water supply in its own country.

Since complete mapping of Northeast Thailand is beyond the scope of this study, a probabilistic approximation of military water-supply potential was generated for the entire region, in terms of distances from a random point to 10-gpm single-source supplies of both surface water and ground water through the seasons of the year.

The RTA Engineer combat battalions do not have as much water-purification equipment in their table of organization and equipment (TOE) as they would probably need if supporting regimental combat teams (RCTs) and associated paramilitary forces in extensive deployment in Phase III (highest-intensity) counterinsurgency operations.

In the larger context of civil water requirements there is a shortage of water wells and potable-water production, but the most conspicuous shortage is in the thorough application of known techniques for exploiting existing water resources. In particular the current haphazard exploitation of shallow ground-water resources is neglectful of their unrealized potential. In no case should local people be deprived of water because of military requirements; sufficient water is available in places accessible to engineer forces. The RTA, however, represents a significant source of potential manpower for carrying out an experimental civic-action program of village-level assistance in exploitation of shallow ground-water resources.

Conclusions

1. There is a shortage of water wells and potable-water production in Northeast Thailand, but the most conspicuous shortage is in the thorough application of techniques to exploit existing water resources.

2. Current US Operations Mission (USOM)-RTG programs for investigating deep ground-water resources are of critical importance in providing not only new sources of fresh water but also the first systematic knowledge of the geology and hydrology of Northeast Thailand.

3. The current haphazard exploitation of shallow ground-water resources is neglectful of their largely unrealized potential.

4. At present the exploitation of surface water seems to offer lower returns than ground water for the development of large numbers of reliable local sources of water for human consumption.

5. Cheap solar stills offer possibilities in the Northeast for the distillation of drinking water from brackish or saline water, but probably they would be practical only where the salt-contamination problem is acute.

6. Sufficient water exists in places accessible to RTA engineers so that local people should not need to be deprived of water because of a military requirement.

7. For counterinsurgency operations, a requirement exists for additional water-purification equipment in the engineer TOE of the RTA.

8. A modern program of systematic collection, analysis, and production of engineer intelligence relating to potential operating areas of the RTA could provide a basis for advance planning for military water-supply development in field operations.

9. The RTA represents a significant source of potential manpower for carrying out an experimental civic-action program of village-level assistance in exploitation of shallow ground-water resources.

Findings

1. The joint USOM-RTG Department of Mineral Resources well-drilling program to tap deep ground-water resources in Northeast Thailand is the mainstay of the permanent development program and should be continued at as great a level of effort as possible.

2. The USOM Public Health and Sanitation programs should be continued at a maximum level of effort so that an improvement in overall water supply will not amount merely to an increase in the supply of contaminated water.

3. A program is urged, utilizing geologists and soils scientists, to determine the distribution, characteristics, and potential productivity of shallow ground-water resources including an inventory of dry-season natural surface-water bodies with attention to location, size, and quality; such a program should utilize air-photo analysis, and any other appropriate remote-sensing techniques including infrared, to define areas of alluvium for rapid testing by power auger or other truck-mounted rotary drilling methods. This program should commence in areas where the deep ground-water exploration program (Finding 1) has not yielded sufficient quantities of water.

4. As a concomitant to Finding 3 it is suggested that a modest research project be undertaken in the feasibility of design and development of shallow large-diameter wells, horizontal infiltration galleries, and other effective shallow ground-water supply systems capable of construction by small

fabricators in the Northeast and suited to the physical character of the water-bearing alluvial deposits of the area.

5. Current RTA engineer TOEs should be augmented by increasing the number of water-purification field units as follows:

(a) Diatomite Portable Water Purification Set No. 3 (35 gpm) from the present allocation of one per regiment or RCT to an augmented allocation of one per battalion or battalion combat team (BCT).

(b) Diatomite Portable Water Purification Set No. 2 (15 gpm, man-packable) from the present allocation of none to an allocation of at least two per regiment or RCT to add flexibility to field operations during higher levels of intensity of insurgency.

6. The feasibility of initiating procedures for engineer intelligence collection, analysis, and production in the RTA Engineer organization should be investigated to assist in planning for field water supply, routes of movement, and other environmental restraints on operations; because the RTG Department of Mineral Resources could be of substantial assistance in such a program, the possibility of cooperation should be studied carefully.

7. The feasibility of a large-scale but simplified civic-action program throughout Northeast Thailand by the RTA, aimed solely at the development of shallow ground-water resources by assistance in the excavation of exploratory hand-dug wells should be investigated in terms of potential total civil impact, useful employment of military forces in low-level counterinsurgency operations, favorable exposure of the RTA in an unstable social situation, and incidental payoff to the Army in terms of knowledge of local terrain and water resources.

Water Supply
for Counterinsurgency Operations
in Northeast Thailand

ABBREVIATIONS*

AID	Agency for International Development
AOR	area of responsibility
BCT	battalion combat team
BPP	Border Patrol Police
FAO	Food and Agricultural Organization (United Nations)
gpd	gallons per day
gph	gallons per hour
gpm	gallons per minute
MRDC	Military Research and Development Center, Ministry of Defense, Royal Thai Government
MSS	mission support site
PFGT	Peoples' Free Government of Thailand (fictitious organization)
PP	Provincial Police
RCT	regimental combat team
(rs)	reduced strength
RTA	Royal Thai Army
RTG	Royal Thai Government
TOE	table(s) of organization and equipment
USDA	US Department of Agriculture
USOM	US Operations Mission (Agency for International Development)
VDC	Volunteer Defense Corps

*Thai currency: 1 baht = 5 cents US (approximately).

INTRODUCTION

Depending on the season (see App A) and the particular part of Northeast Thailand, the probability is that the supply of water is either much too great or entirely too little; seldom is it simply "enough" (App B) throughout this area of seasonal heavy rains and flooding followed by hot sun and dry skies for the remainder of the year. Ordinarily the civil water supply diminishes every year as water levels in streams, standing water bodies, and wells recede throughout the dry season to critically low levels or, in places, until no water remains even in the wells. Thus, water for the steadily increasing population of the Northeast becomes difficult to find at the hottest time of year. Then it must be obtained from whatever sources have not altogether disappeared and are within a few kilometers' walking distance.

Three months later, in the same area, water may be so abundant that wells and streams are filled to overflowing and transportation through the flooded countryside may be as easy by shallow-draft boat as by oxcart. The areas of worst drought as well as those of greatest flooding tend to vary from year to year and unfortunately are not easily predictable. The entire seasonal cycle, however, can raise havoc with the needs and occupations of the people, affecting everything from drinking water to rice farming In many places the supply of water is intermittently undependable for such routine household purposes as cooking, cleaning, bathing, and sanitation. Progress in public health is probably very much dependent on the permanent availability of local civil water supply.

As sketchy as the foregoing may be, it roughs in the general features of the "water problem," which is actually the combined problems of water-resources investigations and water-supply development. A period of years will be required, added to the decade or so already spent, before the first general approximation of the water resources of the Northeast can be completed. After that probably many more years will be required for all the construction associated with surface-water management and water-supply development.

But if the insurgency under way in Northeast Thailand were to intensify, other problems might easily arise. Whatever the specific role of Thai military and paramilitary forces in counterinsurgency operations, the deployment of RTA units would involve logistic considerations, particularly in field water supply and distribution, that have not been addressed previously. The question arises, what sources of water would be available throughout the seasonal cycle of rainy and dry months? How would potential sources vary, and what would be the effect, if any, on water supply to meet civil demand? The answers to these

questions would raise further questions: Will the development of civil water supply help future military operations? Can the military forces be of assistance in temporary water-supply investigation, location, or development? How well prepared is the RTA to locate quickly new water-supply availability on deployment into an area? How well equipped is it to purify water from doubtful or contaminated sources? If problems exist, are they manageable in terms of present RTA planning, TOE, and standing operating procedures?

Finally, are present programs sufficient to deal with the problems? Are current water-resources investigations resulting in progress and improvement? Are any additional kinds of projects or programs needed to utilize the water-resources potential of Northeast Thailand?

The RTG Mobile Development Units operating in the Northeast since 1962 have repeatedly been told by the rural people being helped that the thing they want most is "... more water for drinking."[1] In more formal terms the requirements for development of the Northeast are listed[1] in order of importance as:

(1) Water
(2) Elementary health and sanitation
(3) Teachers
(4) Roads
(5) Agricultural advice and assistance

LaMoreaux (personal communication,* 1966) notes that the situation was essentially the same during his 1955 investigations of water-resources problems in the Northeast, and long before that Pendleton[2] expressed similar ideas both implicity and explicity as a result of his work there before WWII.

Water management and water-supply development, integrating surface-water construction and regulation with ground-water exploitation and recharge, go hand in hand in planning for the rehabilitation and development of Northeast Thailand. Following these come improved sanitation, cleanliness, personal hygiene, and public health from proper water supply; flood control; irrigation techniques; area drainage; modified agricultural practices; and easier construction, in readily floodable areas, of all-weather roads as a result of surface-water regulation and diversion.

In the dry season, water is sold as a precious commodity in some areas at a cost of about 2 bahts (1 baht = 5 cents US, approximately) per 12 gal (reported in the Bangkok World Annual Review, 1965[3]) which amounts to \$8.30 per 1000 gal. This is an interesting comparison with the US and other countries where efforts are under way to reduce the price of drinkable water converted from seawater to about 20 cents per 1000 gal because 50 or 60 cents is not considered economical. In the rainy season a superabundance of water is available at virtually no cost but most of it is polluted and little or none reliably nonpolluted. Expectably, enteric diseases are common, if not almost universal. Information released since the 1960 census by the RTG Division of Vital Statistics, Department of Health, discloses that 90 percent of the rural population has waterborne intestinal parasites, with enormous consequences in terms of lowered vitality and productivity. Additionally, 60 percent of all debility and 40 percent of mortality are attributable to these diseases. Complicating the situation is the fact that the biological origins of infection and disease are not understood by the people and hence, in the vast majority

*For the reader's convenience, all personal communications are listed in the reference list at the end of the document.

of cases, no significant effort is made to purify or decontaminate drinking water. Some restaurants in towns and cities boil their drinking water but serve it with chunks of ice made from nonboiled water.

Either shallow or deep wells in several districts of the Northeast may be salty, and others may be less productive in the dry season. Irrigation works may be inadequate to control and relieve temporary flooding in the rainy season and insufficient at other times to provide the minimum moisture necessary for crops, but dry-season problems are being gradually corrected by construction of surface-water storage facilities. Because of the peculiarities of climate throughout the Khorat Region, with droughts and floods a matter of seasonal certainty, water-supply development has been locally haphazard. The people know that the driest of droughts will change to rain and floods in a matter of time and that the worst of floods will dry out, so that their antidote for either inconvenience is just to wait until the inevitable change occurs. Planning for the excavation and construction of a dependable water-supply system is difficult for a technically unsophisticated people because of the complex hydrology generated by such pronounced climatic variation.

In the mid-1950's the RTG began the work of vesting the northeastern third of the nation with the means to develop its resources; to improve its agriculture and productivity; to establish transportation for commodity marketing, centers for distribution of goods, and communications between villages, towns, and provinces; and to restore and ensure the health and well-being of the people. How long this will take in Northeast Thailand, endowed with a less-than-ideal geology and climate, will depend on the imagination, diligence, and vigor with which the work is carried through to completion. By several measures of criticality, water-supply development seems to be a first step without which other important ones cannot follow.

The RTG is making a large and impressive effort to address these problems in the Northeast. The many ministries concerned are working together both at cabinet level and in lower-echelon committees to improve living and economic conditions in the entire region. Technical and financial assistance for many of the programs is being given by various US and international agencies. Figure 2 diagrams the principal RTG branches and their relations to cooperating foreign agencies concerned directly or indirectly with groundwater, surface-water, and water-supply development in Northeast Thailand. The respective fields of interest and effort indicated in Fig. 2 are continuously changing and evolving, as are the relations between agencies; therefore the diagram cannot be completely specific for the long term. It does, however, suggest the magnitude of the effort and the complexity of cooperative arrangements.

In terms of the basic needs of the civil population as well as in terms of agricultural and economic progress leading to social and political stability, Fig. 3 perhaps illustrates the general situation. The point is that with outside assistance over a period of time, Northeast Thailand could change from a depressed and poorly developed area into a more self-sustaining society having an improved tax base and some hope of economic progress.

The studies embodied in the present report were performed during the period January–March 1966 by the authors while on temporary assignment to Bangkok, Thailand, as a part of the Advanced Research Projects Agency Project AGILE, and under the auspices of the Military Research and Development Center of the Ministry of Defense, RTG. Field observations were com-

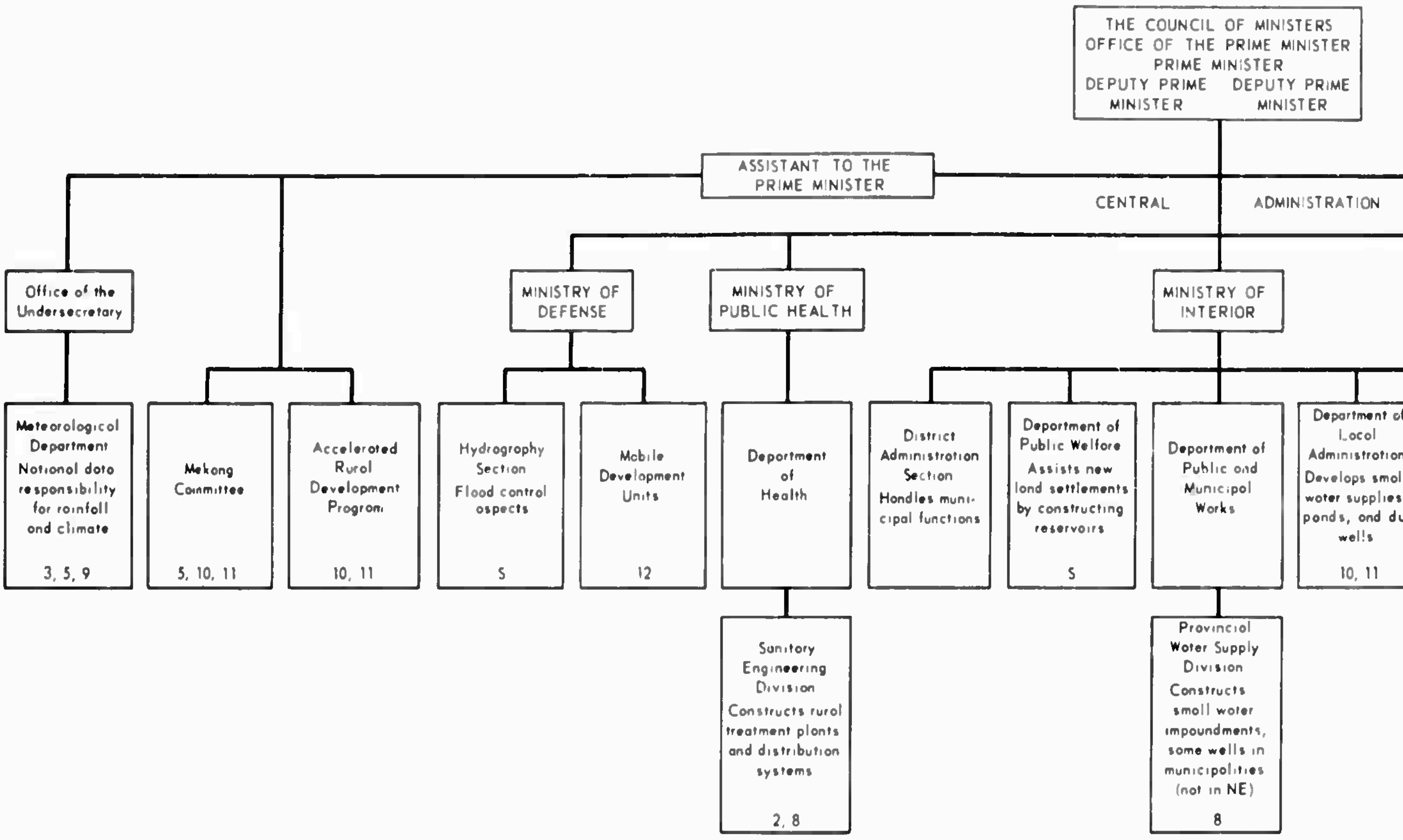
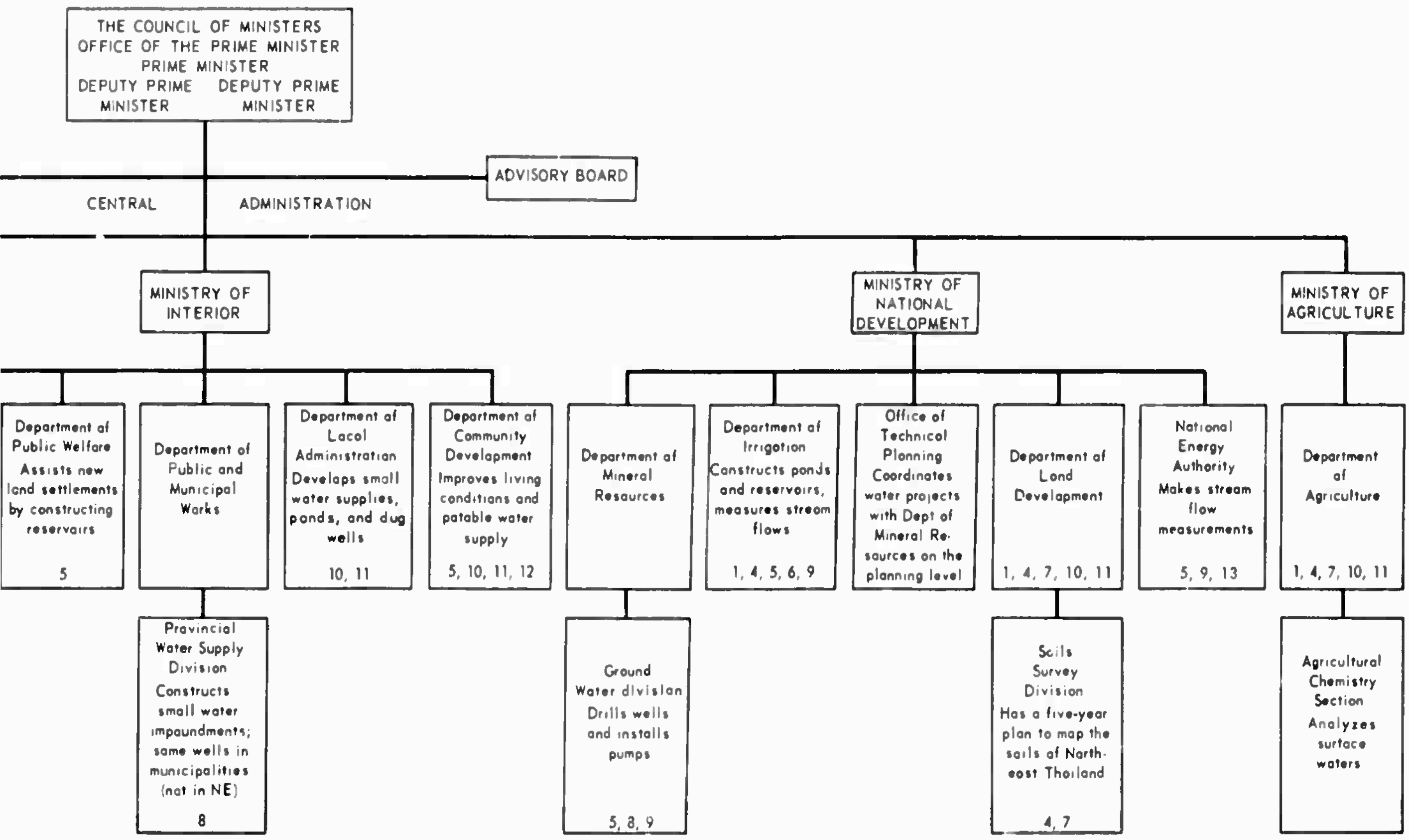


Fig. 2—RTG and Cooperative International and US Agenci
Water Supply Development

Numbers in boxes indicate the primary international and US coo|
listed in the accompanying tabulation.

Number	Agency	Number	
	International		Age
		7	
1	Colombo Plan	8	
2	World Health Organization (WHO)	9	
3	World Meteorological Organization (WMO)	10	
4	Food & Agriculture Organization (FAO)	11	
5	Economic Commission for Asia and Far East (ECAFE)	12	
6	International Bank for Reconstruction and Development (IBRD)	13	



ooperative International and US Agencies Concerned with Water Supply Development

icate the primary international and US cooperating agencies as listed in the accompanying tabulation.

	Number	Agency
		US
		Agency for International Development (AID), USOM
	7	Agricultural Development Division
	8	Public Health Division
	9	Capital Projects Division
IO)	10	Rural Roads and Village Projects Division
))	11	Equipment Division
or East (ECAFE)	12	Social Development Division
and Development (IBRD)	13	Special Coordinator, Office of the Director

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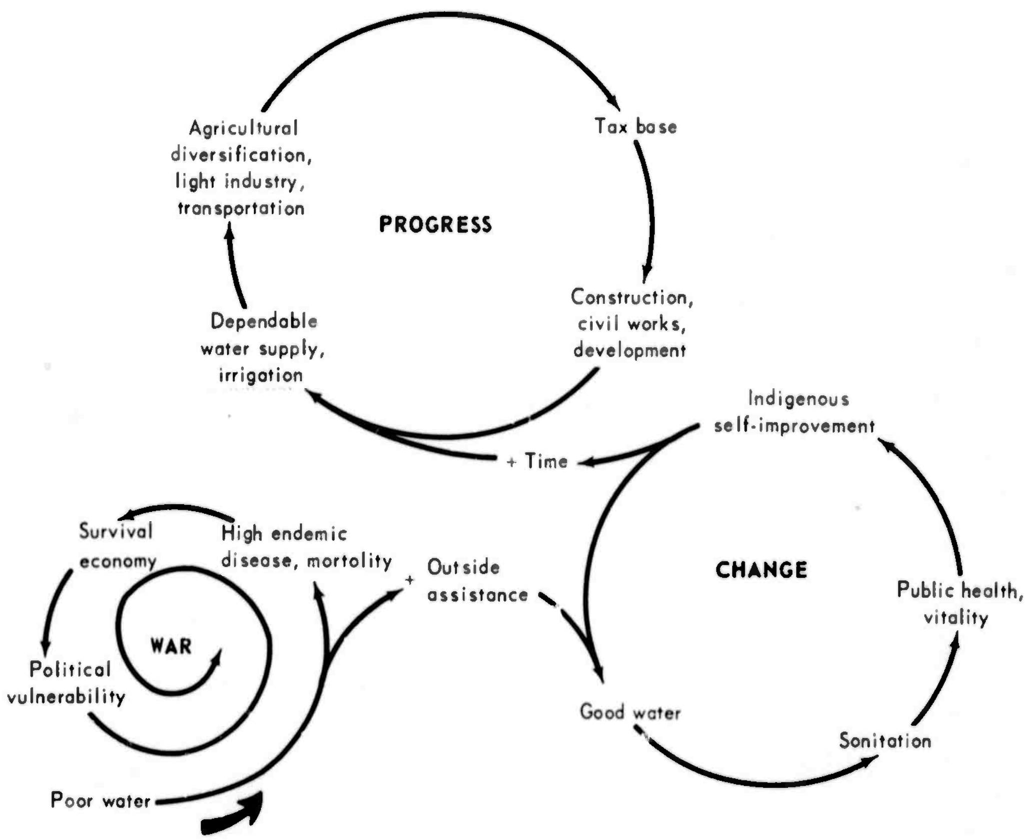

Fig. 3—Economic-Improvement Model

"Worst case" and "best case" in gross simplification. Although a solution to the water-supply problem is not the answer to all problems of economic and social improvement in Northeast Thailand, the water-supply situation is inextricably involved with all the other problems, the solution to each of which is probably a necessary but not sufficient condition for overall progress.

bined with analysis of results of research being performed by several different Thai, US, and UN agencies or authorities. The overall direction of effort was aimed first at problem definition, details of which are given in the appendixes to this report, and second at an orderly examination of future possibilities based on current activities and accomplishments. It is emphasized that this document is not intended to report any formal hydrologic investigations by the authors but rather to provide a summary of what is known to date and an evaluation of its significance to counterinsurgency operations in Northeast Thailand.

Similarly the planning sequence and operations projections (App C) designed to furnish demand criteria for military water supply are virtual rather than actual. No access has been requested or granted to any Thai, US, or Southeast Asia Treaty Organization (SEATO) military plans affecting Northeast Thailand. Allocation and deployment of forces are simply as realistic as possible under the circumstances envisioned, which are solely for purposes of the present study.

THE LOGISTICS OF WATER: PLANNING AND OPERATIONS

THE PROBLEM OF WATER SUPPLY IN MILITARY PLANNING

As in any kind of planning for whatever purpose, military planning for subsequent operations must project problems, pose questions, and furnish satisfactory answers to those questions. What is the objective in an overall operation? What must be accomplished? How large a force will be required? Where will the operations take place? What physical environment will be encountered? What constraints will be exerted by the environment on combat operations such as weapons employment, movement, and communications? Similarly what will be the environmental constraints on logistic factors such as depot construction, material storage, transport, and, pertinent to the purpose of this discussion, water supply?

Military water supply throughout the history of warfare has presented a problem to those fighting and, increasingly, to those planning. Pure air supply is not ordinarily a problem in operations, but food is enough of a problem or potential problem that it is carried as a standard item into the field. Although many armies in many ages have foraged for food, this is not the most efficient or reliable way of obtaining rations. As a consequence much research and development is invested in the design, procurement, manufacture, and supply of easily storable and transportable food rations to troops in the field. But what of the "in-between" necessity, water, which is neither so easy to obtain as air to breathe, nor so practical to handle that it ordinarily is shipped from great distances as a standard logistical supply item to each and every soldier in the field?

A critical military tradeoff exists between natural availability of water in the combat theater and the total cost of bringing enough water to satisfy the entire requirement from some significant distance. In many or most theaters the probability is fairly high that enough water will be available most of the time, but this is by no means a certainty, nor will water be found in every place. Measured against this is the certainty of high military cost of bringing water into the theater, including acquisition and weight costs; additional vehicles or other units of transport; distribution; and the high overall vulnerability of such a system to destruction or sabotage with consequent effects on viability of the forces deployed. In general it has proved feasible to rely on local water availability because of the high cost of bringing it in, but as military operations become more efficient and the necessity increases of avoiding foreseeable failures at any "reasonable" cost, a mounting premium is paid to ensure

the probability of success of exploiting water resources not only within the theater but as close as practicable to the battlefield. A large part of this premium is the intelligence effort devoted to engineer operations such as water production based on the collection and analysis of large quantities of environmental and technical information.

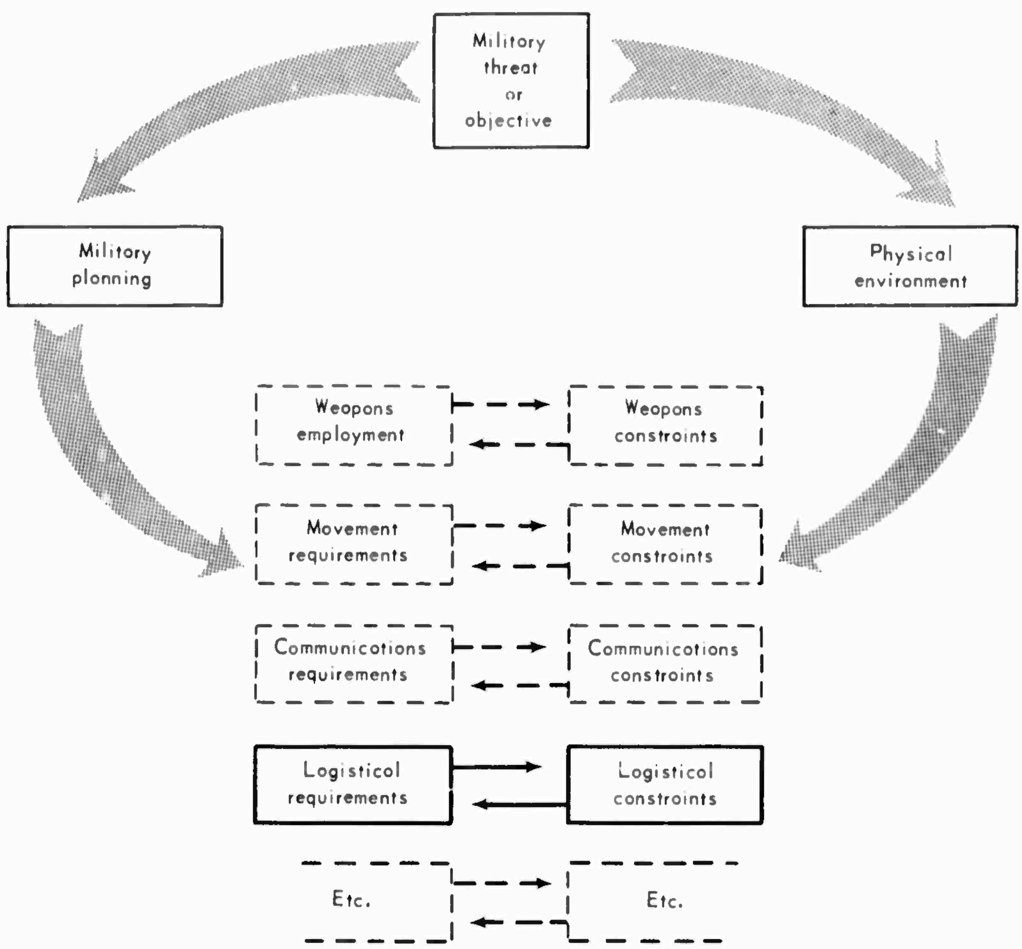

Fig. 4—General Relation between Projected Operations and Environmental Constraints in the Area of Operations

The emphasized logistical phase is considered in greater detail in Fig. 5.

A simplified diagram (Fig. 4) shows the generalized logistic problem in planning and some accompanying military factors that are subject to environmental constraints. This diagram specifies that a general relation exists between the characteristics of the environment and the military operations that

can be accomplished with the requisite efficiency or success within that environment. "Planning" endeavors to consider this relation in order to anticipate and forestall potential restrictions that could lead to failure.

From this general statement it is then convenient to respecify and resolve the logistic considerations involved in supplying water for a military force in such a place as Northeast Thailand, using the same scheme of relations in more concrete terms (Fig. 5). This diagram depicts on one side the general sequence of military considerations in the chain originating with threat

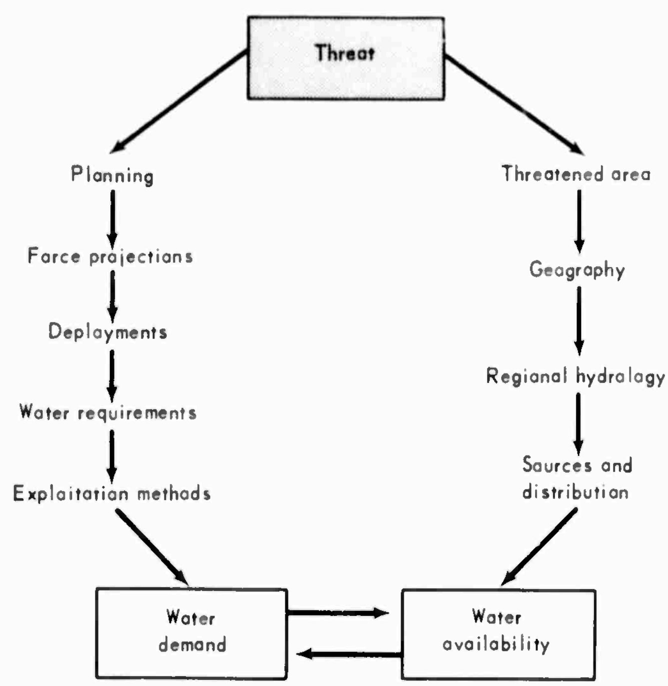

Fig. 5—Logistic Approach to the Problem of Military Water Supply
Emphasizing the logistic part of Fig. 4 in more specific terms.

and terminating with projected water demand for support of operating forces in the area. The other side shows the sequence of analysis leading to evaluation of potential water availability for military purposes. It is a fundamental premise of this paper that in order to understand the relations between water demand and water availability it is necessary to investigate thoroughly the derivations on each side of the diagram.

Other sections of this paper treat the overall environment in terms of the status of ongoing research, including both research in hydrology and research on related environmental topics that have a major bearing on hydrology and water resources.

Operations and Responsibility

The RTA Second Army Area, comprising the 15 provinces of Northeast Thailand, is occupied principally at present by the 3d Inf Div (App C). This is divided into three RTCs at Khorat, Udon, and Ubon, respectively. The RTA Eng Bn (Fig. 6) supporting the division has its headquarters company and one combat engineer company at Khorat with 3d Div headquarters and another combat engineer company also at Khorat supporting the RCT garrisoned there. Third and fourth combat engineer companies support the RCTs at Udon and Ubon.

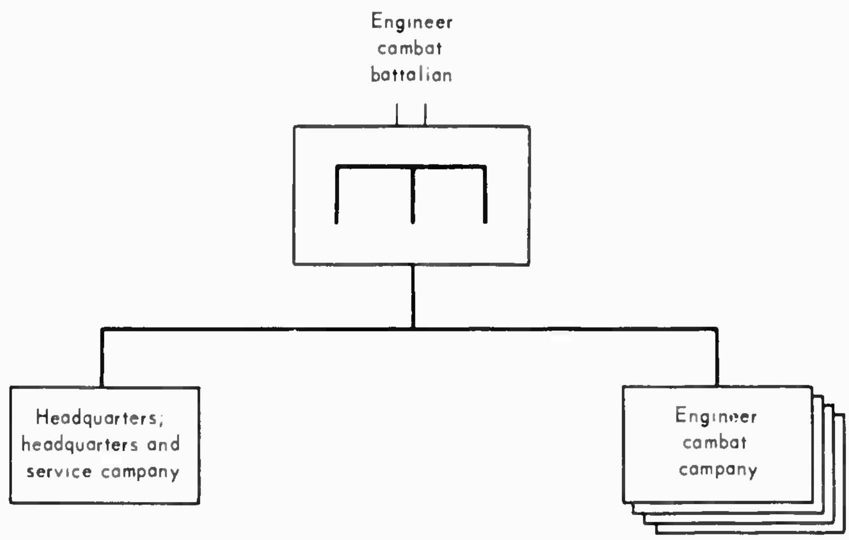

Fig. 6—Organization of RTA Engineer Combat Battalion

Although these engineer companies must cope with problems of water supply in garrison from time to time, such problems are not continuous and largely involve well or well-field operation and maintenance. When the RCT moves into the field, however, engineer problems change abruptly, for it is an Engineer responsibility to provide "drinkable" (not necessarily potable) water to all the units of the RCT. This involves setting up a water point in the field, including the location of a water resource, processing raw water through filtration and purification, and making potable water available in appropriate quantities to each company and battery in the RCT. The supply officer (S4) of the RCT is responsible for issuing to the engineer company the directive to establish a water point at or near a particular place or in a given area. During water production and distribution at the water point, each battalion S4 is responsible for managing the water pickup and delivery to consuming units.

For smaller deployments, such as a battalion, the battalion S4 may have to direct the establishment of a water point, with management of water pickup at company level.

Equipment

Engineer-combat-battalion TOE show four portable water-purification-equipment sets each rated at 2100 gph output, or 35 gpm. Thus each engineer company supporting an RCT has one of these sets for supplying battalion needs, but it is noted that they have nothing lighter or smaller than this unit, which requires a 1½-ton 2-wheeled trailer, towed by a 2½-ton truck. This purification set is batch-type rather than continuous-flow equipment and consists of a pressure filter unit with a diatomite filter-aid feed apparatus, precoat tank, four gasoline-engine-powered portable pumps, three 3000-gal collapsible fabric tanks, appropriate suction hose for intake and connections, a supply of coagulating chemical reagents, calcium hypochlorite, diatomite filter aid proper, chemical feed baskets, measuring container, and a chest containing discharge hose, fittings, and pH and residual-chlorine test equipment. The entire equipment set is stored on both trailer and truck. Output rating is an expectable average based on successive batches of water.

Without exhaustive consideration of the chemistry, physics, and biology of water purification it is nonetheless necessary to note briefly that military water-purification-equipment sets used by the RTA, as well as by the US Army, ordinarily are capable of water treatment by coagulation, filtration, disinfection, and, if necessary, sedimentation. Coagulation is achieved with chemical flocculants to remove fine suspended matter from the raw water. Filtration through ultrafine diatomite removes suspended matter, microbial contaminants such as amoeba and amoebic cysts, schistosomes, and some bacteria. Chemical disinfection is necessary after the previous steps and is commonly done with calcium hypochlorite to put chlorine into solution, which is not only lethal to contaminating organisms but affords measurement of its effectiveness by simple chemical test. Sedimentation can be employed to remove coarser particulate matter, if necessary, using tanks for sedimentation before starting coagulation. Processing and testing procedures have been standardized for each step in water purification for military supply, with the RTA adhering to standards established for the US army.

Exploitation Methods

Water-purification-equipment sets have intakes generally consisting of strainers on the end of suction hose that must be placed in a water source of some kind, be it stream, lake, pond, river, spring, reservoir, or shallow or deep well. Lest this seem too obvious, it is necessary to consider the other requirements for a military water point, such as concealment, accessibility, and cover for personnel; facilities for vehicle cover, concealment, parking, and turnaround; good drainage of the site, bearing capacity for heavy wheel loads, bivouac for personnel, and overall security. Most water points cannot be expected to possess all these desirable features, but they must be adequate and appropriate to the military operating situation. Moreover the quantity and quality of water must be considered. That is, a sufficiency of usable raw water must occur at the site, with due allowance for seasonal variation for semi-permanent sites, and consideration must also be given to layout, operations, and safety in case of sudden or unexpected precipitation or rise in water level.

Similarly the raw water must be of such quality that purification is practicable with normal field equipment. This can be determined either with testing kits or by careful judgment of color, odor, taste, turbidity, and observation of possible indications of pollution such as chemical damage to vegetation, presence of dead animals, and proximity to waste, sewage, or sewage outflow.

Intakes must be emplaced carefully in any water body and secured firmly in flowing water. In some situations small dams, weirs, or barriers help to increase depth of water. In others, coarse gravel packing around the intake strainer aids in stability and strains out sediment. Flotation can be used by attaching the intake to a small anchored pontoon. In wells of small diameter the intake may be reasonably stable. In wells of larger diameter, such as many dug wells, the intake and suction hose may have to be secured by lashing or props to avoid spiraling during pumping that could result in aggravation of turbidity or damage to the intake.

Whether for exploiting surface water or ground water the site must be chosen carefully, the equipment set up, the intake emplaced, and purification begun. First batches or the beginning output of continuous-flow purification are watched and checked carefully to ensure against malfunction, breakdown, or inadequate processing, in addition to undergoing normal chemical test procedures. Storage tanks are filled with purified water ready for pumping into water trailers. For heavy military demand at major water points, turnouts and turnarounds are constructed to facilitate rapid loading and dispatching, and auxiliary storage tanks may be built either at ground level or on elevated trestles.

Much of the foregoing applies particularly to operations in conventional warfare, with an implied necessity for adapting when possible and feasible to the requirements and constraints of unconventional warfare in the conduct of counterinsurgency campaigns. Conceivably the lack of roads in Northeast Thailand or the impassability of some roads in the rainy season might require off-road (cross-country movement) approach for vehicles to reach the water point. Wheeled water trailers might need to be pulled by tracked vehicles or in rare circumstances water containers might need to be carried in a tracked vehicle such as the M113 armored personnel carrier. Finally, considering the logistics of quick-response deployments in counterinsurgency and the presumed availability of helicopters, water for satisfying troop requirements could be transported by air. None of these eventualities is highly probable, but all are possible and deserve consideration in the context of expediency and contingency.

WATER RESOURCES IN NORTHEAST THAILAND

SUMMARY OF PROGRESS OF INVESTIGATION

The briefest summary possible of the results of investigations of the surface-water and ground-water resources of Northeast Thailand is presented below. For complete information and analysis see App A, "The Physical Environment of Northeast Thailand," and App B, "The Hydrology and Water Resources of Northeast Thailand," in which all the pertinent topics are presented. The following information is intended only as a résumé of the water-resources situation as it becomes involved in subsequent sections of this paper.

Deep Ground-Water Resources

Investigations of deep ground-water resources have been conducted jointly by the RTG Department of Mineral Resources and USOM through a drilling and mapping program. A summary of statistics available 31 December 1965 on wells drilled in the Northeast is given in the accompanying tabulation.

Years	Wells drilled	Water quality
1955–1963	1101[a]	Good, 71%; brackish, 8%; too salty, 14%; dry or mechanically unbalanced, 7%
1 January 1964–31 December 1965	499	No information available

[a]Statistics are available only for the 1101 wells drilled before 1 January 1964.

For the 768 wells that were producing at the end of 1963:

(a) 55 percent yielded less than 25 gpm
(b) 26 percent yielded 25 to 29 gpm
(c) 13 percent yielded 59 to 99 gpm
(d) 6 percent yielded 100 to 120 gpm

The average depth of wells is less than 300 ft, and most wells drilled in rock in Northeast Thailand show at least some artesian rise of ground water.

It should be emphasized that the statistic given in the tabulation showing that 71 percent of successful wells yielded good water is somewhat misleading; the ratio of good wells could be significantly higher. Many of these wells were drilled as part of regional reconnaissance, some only for the purpose of obtaining stratigraphic information.

The projected rate of drilling for 1966 would result in 300 new wells or one exploratory well every day of a 6-day work week throughout the year. However, even this rate may need to be augmented over the next few years to satisfy the demand. Regional mapping of ground-water resources by the Department of Mineral Resources is projected to cover approximately two provinces per year.

Shallow Ground-Water Resources

Lying within the widely distributed and easily excavated alluvial soils of the Northeast, shallow ground-water resources may well represent a larger potential supply for domestic use than has been realized. This resource originally was somewhat underemphasized in formal water investigations, partly because of an incomplete understanding of the geological nature and total extent of these alluvial deposits. The emphasis by the limited (but very capable) hydrology staff of the RTG Department of Mineral Resources was primarily on the development of the deep ground-water supplies that in the long run were thought likely to show greater production and less seasonal variation, and also to be easier to protect against contamination. By 1961, however, it was recognized that exploration for deeper ground water (summarized under the preceding heading), although successful, was yielding less water than had been sought. Reconnaissance evaluation at that time also indicated that thousands of dug wells existed throughout the Northeast, but a great majority of these were located improperly with regard to geologic and hydrologic factors and were subject to easy pollution. Actually, many of these dug wells were hardly more than rather crude pits dug in the ground (LaMoreaux, personal communication). Thus, with the thought that a substantial number of additional shallow ground-water supply sources could be developed over a large area of the Northeast by using appropriate exploration and development techniques, effort was redirected to a closer evaluation of alluvial materials, particularly along the major river systems.

The problems involved in better exploitation of the shallow ground-water resources, together with a multiple approach to the solutions of these problems, are shown in model form in Fig. 7. Immediate improvement of known supplies could probably be effected as indicated on the left-hand side of this model. Many existing wells could be improved by deepening them slightly, in many cases by only 2 or 3 m, to reach below the dry-season ground-water level. Furthermore the development and use of infiltration galleries, and in some cases large-diameter dug wells, could be useful in increasing the quantities of water produced from shallow aquifers or those with low specific capacities (slow yields). Furthermore in some areas large supplies might be made available through induced recharge by digging or boring into the floodplain materials of existing rivers. Finally, it should not be overlooked that these shallow ground-water resources are so shallow in many places that they would be accessible to rapid or emergency exploitation through the use of explosives for cratering into the subsurface water body. Exploration for shallow ground-water resources is to a considerable degree dependent, first of all, on the identification of areas of alluvium suitable for the accumulation and storage of water, a problem overlapping the fields of geology and soils science. The systematic analysis of

vertical air photos of mapping quality, even if 10 years old, would greatly increase the speed and accuracy of investigation. The use of jeep-mounted 6- to 8-in. power augers would probably be ideal for rapid drilling to afford evaluation of yield, drawdown, and quality of water.

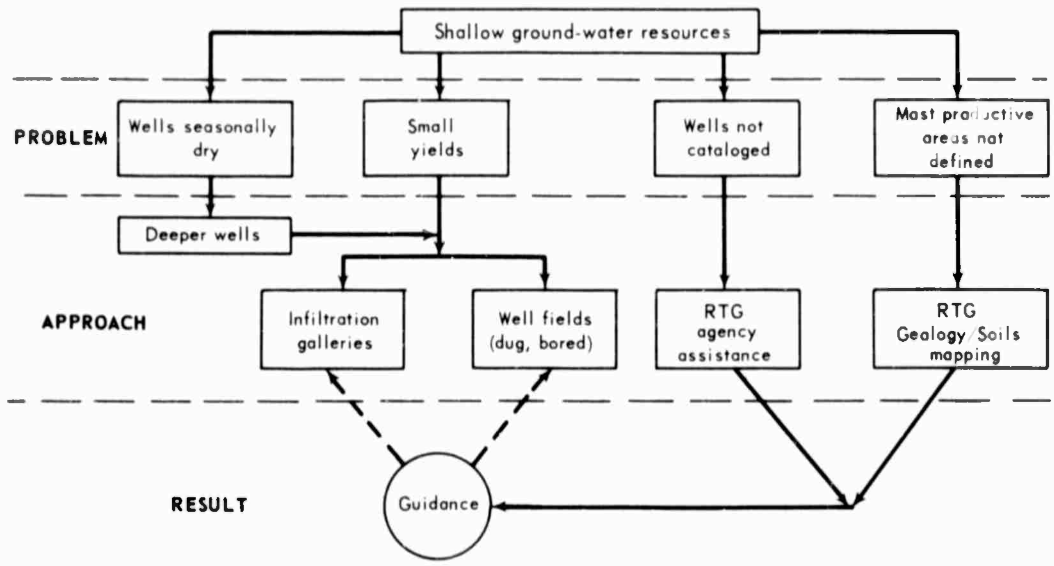

Fig. 7—Simplified Model for Development of Shallow Ground-Water Resources

Surface-Water Resources

Surface-water management and development programs in the Northeast are not only extensive but increasing in terms of construction effort. Surface water is of less significance than ground water for domestic supply in the many thousands of villages throughout the region, but there is of course no gainsaying the importance of these resources, particularly in irrigation with the contingent agricultural benefits and economic improvements. Beyond this, surface water is quite necessary and convenient for stock watering. In some places surface water may represent the only potential supply of potable water. The increasing use of special linings in reservoirs and irrigation systems to prevent water-infiltration losses and the use of antievaporant monomolecular surface films hold as much promise for Thailand as ywhere for the conservation of surface-water resources. Unlined irrigation works such as canals and ditches can pose a serious threat in areas of even mild near-surface salt content by accelerating the diffusion of salt ions upward into the soil zone where seasonal cyclic evaporation can cause damaging concentrations. The distribution, size, and quality of natural surface-water bodies in Northeast Thailand, particularly at the height of the dry season, is currently not well known. A need exists for comprehensive inventory of these waters.

Salt Contamination

As noted in several places in this study, problems of water-supply contamination by salt (sodium chloride) are diminishing somewhat with increasing technological skill in well management by which contaminated subsurface producing horizons are bypassed in favor of uncontaminated ones. Also the gradual realization that, if deep ground water is contaminated, shallow ground water need not be, and vice versa, has resulted in production in some areas of potable water where none was thought possible. In spite of all this it seems that a few places in the Northeast still must use salt-contaminated drinking water, from either ground or surface waters, that is detrimental to people and livestock. Recent progress elsewhere is of great interest in the cheap distillation of brackish or saline water by solar stills, using wooden or metal troughs, transparent or translucent plastic sheeting, and sunlight as energy to produce potable water. It is possible that an inexpensive system can be made effective enough to relieve the need where not acute.

DISTRIBUTION OF WATER SOURCES

Surface Water

As discussed in detail in App B of this study, surface-water sources for military exploitation vary with the seasons of the year. In the rainy season's later stages, particularly from August to December or January, surface-water runoff is well developed and accounts for a significant proportion of regional water loss. Surface-water sources are not only available throughout most of Northeast Thailand but so much so that the principal part of the military exploitation problem may be to find a place with sufficient drainage and bearing capacity for establishment of a dependable accessible water point. Most or all of the streams depicted on standard military maps at 1:250,000 and 1:50,000 scales are flowing to some extent during these months, whether shown as perennial, intermittent, or ephemeral. Relatively few 10-km UTM grid squares in the entire Northeast do not show at least one potential surface-water source.

From December–January to April–May surface-water discharge diminishes, all ephemeral streams are dry, and most intermittent streams contain only puddles or pools of water at best. Flow occurs only in the channels of major rivers and streams because evaporation is especially rapid not only of what little rainfall occurs in this season but also of much that has fallen before. Stream and river water levels can be expected to fall 25 ft. Statistical absolutes are at best elusive within the changing landscapes and dry seasons of the Northeast but as an estimate it is believed probable that an engineer unit would have to search 50 to 100 km from most random points to find a usable source of flowing water at the height of the dry season. However, many nonflowing sources suitable in quantity for smaller demand and raw-water utilization occur generally throughout the countryside. Assuming the frequency of nonflowing potential surface-water sources to approximate at least 10 times that of flowing sources, it would be expectable that a usable source could be found within 5 to 10 km of most random points. Actually, although much more

susceptible to contamination, these nonflowing sources in many places are an exposed ground-water body in a hole or depression, and their potential yield may be much higher than the visible quantity of water. Many agricultural tanks and ponds are available for minor withdrawal, but consent from their owners would be desirable. More of these are being built every year; although some are probably abandoned as impractical, the total number is increasing.

Finally, the period each year from April–May to July–August is probably the least predictable. As the rains increase, ground-water levels rise first taking most of the water before much surface-water flow begins. Moreover, ephemeral flow of a few hours in direct response to precipitation can provide momentary sources for small-scale exploitation from time to time, but anticipation of these opportunities is difficult. No easily verifiable predictive method is available for describing reconnaissance requirements, in terms of distances from a random point, for an engineer unit seeking a source. What can be said is that the probabilities are much greater than in the dry season, but not as great as in the August–January period.

Surface-water sources have some probability of salt contamination within the two secondary geologic basins of the Northeast: the small one north of the Rhupan Range including parts of Udonthani, Nongkhai, and Sakhon Nakhon provinces, and also the larger southern basin including the Chi and the Mun Rivers. Salt contamination does not occur in the areas of relief peripheral to these basins. Within these areas of relief, moreover, more streams occur than within the enclosed basins.

Ground Water

To summarize the information presented in the cognizant section of this study, ground-water resources are not only plentiful but widespread in Northeast Thailand in terms of current and immediately foreseeable needs. They are of two general kinds, shallow and deep, not entirely exclusive in position, depth, and behavior, but enough so to be separately identifiable and recognizable on the basis of current hydrologic investigations.

Although more than 1600 wells were drilled in the Northeast in the 10 years preceding 1966, the 300 additional wells scheduled for 1966 should help to develop even more the picture that is emerging of rather large deep ground-water resources exploitable at various depths depending on location (Fig. B11). The wells that have been dug, or occasionally drilled, into shallow ground-water bodies are literally innumerable and probably date back hundreds of years. These are not easily assessed without very large-scale well surveys, but they tap a resource that has much more to offer than has been utilized so far.

The 1600 "deep" wells are located by hydrologists of the Royal Thai Department of Mineral Resources in cooperation with USOM and tend to be along or near roads capable of carrying the heavy-duty drill rigs that are needed. Distribution of these wells is fairly complete throughout the Northeast with an understandable tendency toward grouping around population centers and a conspicuous sparseness of locations in several regions: western Chaiyaphom, western Khon Kaen-Loei, and western Udonthani provices; much of Nakhon Phanom Province. The largest proportion of these wells produces good usable water in quantities ranging roughly from 2 to 1000 gpm. These wells are not

greatly impaired by seasonal fluctuations and are potentially good RTA water points, with new ones being created every year.

Wherever people have established a village there either is or has been some supply of water, commonly from dug wells or deep reservoirs in the shallow ground-water bodies that are discontinuous but multitudinous throughout the Northeast. Such resources range in depth from at or near the surface down to 50 ft or more in unconsolidated alluvial material easily workable with hand tools and power tools. In most places the shallow wells are not properly

TABLE 1

Water-Supply Availability

a. Surface-Water Availability

Season	Distance from surface-water source, km[a]	
	Flowing	Nonflowing
August–December	10	5
January–May	50–100	5–10
June–July	10–50	5

b. Ground-Water Availability

Season	Distance to ground-water wells[b]		
	Shallow ground water	Deep ground water	
		Along major roads	Cross country
Wet	1 well per 12 km^2 or 3–5 km in a specific direction		
Dry	1 well per 25 km^2 or 7–10 km in a specific direction	1 well per 15 km	1 well per 50 km

[a]Probable distance from a random point in Northeast Thailand to a 10-gpm single-source supply of water.

[b]Approximate distance overland in Northeast Thailand to existing wells. New shallow ground-water wells can be excavated quickly in response to field-deployment requirements; deep ground-water wells cannot. A minimum of 10-gpm availability is assumed in all cases.

designed or adequately maintained. Many are not quite deep enough to cope with seasonal rise and fall of the water level, which begins to fall in November and may not rise significantly until June, July, or August, depending on seasonal climatic events. The months of February, March, and April are the times of seasonal low water levels, and dug wells should be continued below the local water level of this period. Water levels can be expected to fluctuate in places as much as 10 or 15 ft and in a few areas possibly even more, but the resource is there. So far as maintenance is concerned, wells such as these require lining, surface barriers to wandering animals, and strict enforcement of sanitation at and near each well site for distances of at least 100 ft and preferably much more. Otherwise wells may fill in as excavated faces ravel; dead animals

and other debris may accumulate at the bottom; and various other contaminants may be introduced into the shallow ground-water body by human carelessness. With these precautions many or most of these shallow wells are potentially very good low-to-medium-yield water sources in the dry season and high-yield sources during the remainder of the year. Availability of surface-water and ground-water sources is summarized in Table 1.

Salt contamination in both shallow and deep water production is a local problem that seems to be getting better rather than worse. Newer drilling and casing techniques and better selection of producing zones have reduced the seriousness of the problem. If a shallow resource is salty, a deeper resource in the same place may not be if properly produced and vice versa. Research in these techniques continues (Bangkok Post, 1965;[4] Jackson, et al, 1965[5]), and holds much promise. Military water-purification sets cannot make salty water potable; distillation is required. But, even so, the distribution of potential shallow ground-water sources for military water points is very wide throughout the Northeast.

WATER SUPPLY FOR COUNTERINSURGENCY OPERATIONS

DEPLOYMENT AND WATER REQUIREMENTS

General

Through successive levels of insurgency, appropriate military measures including deployments are required according to the character and intensity of the insurgent effort. No two insurgencies are alike, but common features characterize the progress of most of them. These are iterated in varying ways, but for purposes of this study the definition of levels of intensity of insurgency are those established by the US Army (FM 31-22, 1963;[6] US Army Special Warfare School ST 31-176, 1964),[7] in which three sequential stages of increasing activity, defined as Phases I, II, and III respectively, culminate in the employment of relatively large organized maneuver elements in a war of movement against established authority.

These phases of insurgency, actual and potential, are treated successively (see App C, "Northeast Thailand: Background Information and Scenario") in the context of Northeast Thailand in the present and foreseeable future, considered in terms of organization of military and paramilitary forces of the RTG. Force structures, deployments, and water requirements are generated in response to insurgent activity and threat assumed reasonable and plausible at the appropriate levels of intensity. The analysis takes the form shown in Fig. 8.

Force levels and deployments as well as unit structures and strengths are approximate and can be misleading if interpreted for purposes other than those of this study. A breakdown of assumed unit strengths is shown in Table 2. Two paramilitary organizations are considered, the Provincial Police (PP) and the Border Patrol Police (BPP). No attempt is made to indicate all the separate stations and strengths of the PP or BPP; instead a general relation is assumed overall between Army strength and police strength whereby total police strength is always half the strength of total Army forces deployed. Volunteer Defense Corps (VDC) is not considered in this study because of its fixed-base location with accustomed local water supply.

Table 2 lists the strengths of RTA units discussed in the scenario-type force projections for each phase of insurgency. The strengths shown are very approximate and based only on general organization, not on specific TOEs.

The complete scenario is developed in App C. Deployments of the RTA and paramilitary forces generated there are presented below without all the related data and substantiating information in the scenario.

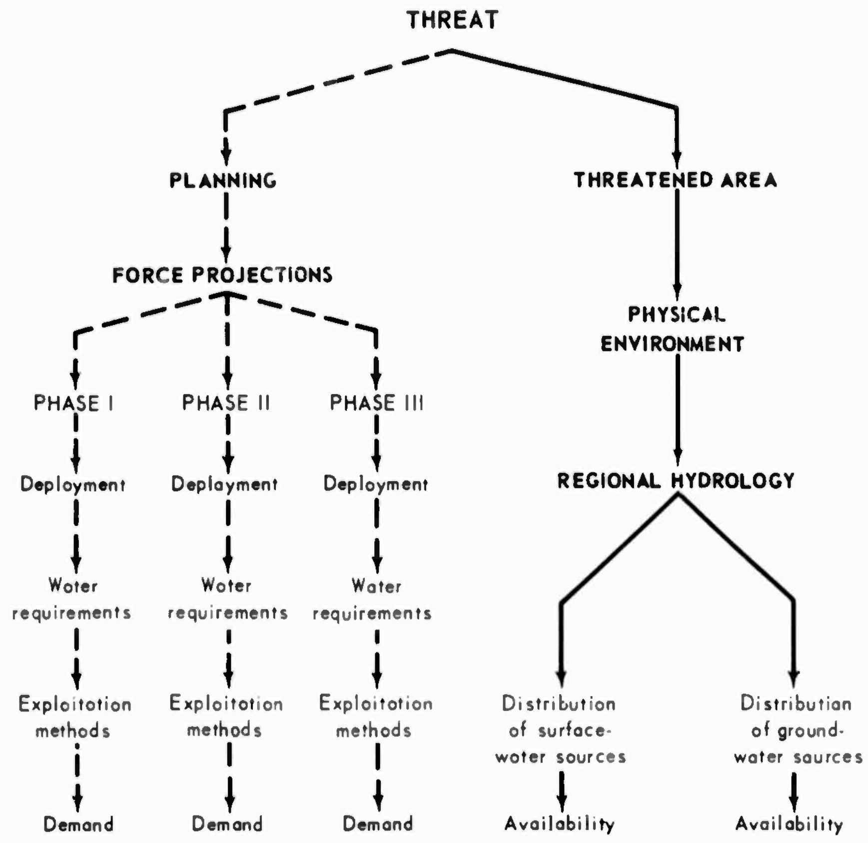

Fig. 8—Relation between Planning and the Physical Environment: Method of Resolution to Consonant Criteria for Analysis of Military Water Supply

TABLE 2

RTA Unit Strengths in Scenario-Type Force Projections

Unit	Approximate strength
Rifle company	200
Rifle company, reinforced	300
Infantry battalion	900
BCT [reduced strength (rs)]	1000
BCT	1200
Infantry regiment	3500
RCT (rs)	3800
RCT	4500
Cavalry squadron, pack	1300

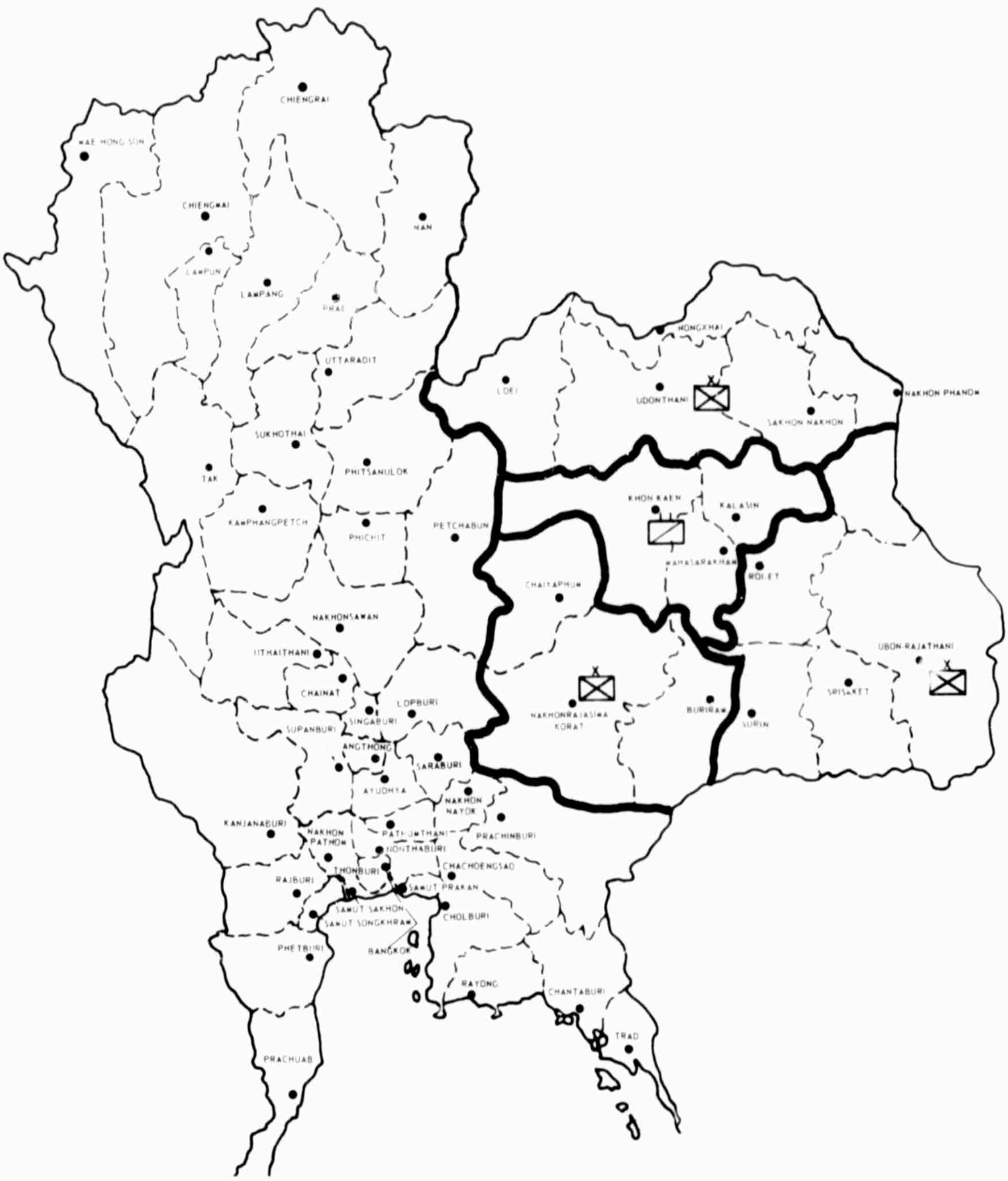

Fig. 9—Phase I, RTA Forces and Deployments
Scenario 1959–1966.

Boundary of area of responsibility (AOR) for unit indicated RCT

Cavalry squadron (pack)

Phase I Water Requirements

Effective RTA forces include (Fig. 9) an RCT at Khorat, an RCT at Udonthani, and an RCT at Ubon Ratchitani and a pack cavalry squadron at Khon Kaen, all in garrison. It is assumed that, in Phase I, paramilitary forces such as PP and BPP operate independently and ordinarily do not rely on RTA support for water supply. Potential Phase I deployments out of garrison, discussed in App C, would develop water requirements similar to those assessed under Phase II. However, troop water requirements as a general problem are addressed in the following paragraphs as background to analysis under subsequent headings.

The water-consumption requirement in Table 3 shows how much water per man is needed in various situations. In garrison, for example, an entire RCT might be expected to use as much as 100 gpd/man or 450,000 gal in 24 hr. This requires either one source producing more than 300 gpm or several smaller sources, which is commonly the case in base development and construction.

TABLE 3

Troop Water Requirements

(Modified from US Army TM 5-700[8] and adopted by RTA)

Mode	Requirements per man, gpd	Qualifying factors
Combat, austere	½–1	Operational ration; should not exceed 3 days without augmentation
Combat, relief	2	If using field rations
	3	Drinking water plus small amounts for cooking and hygiene
March or bivouac	2	Minimum for all purposes
Temporary camp	5	Drinking and cooking; no bathing
	15	With bathing
Semipermanent camp	30–60	Includes allowance for waterborne sewage
Permanent camp	60–100	

An infantry battalion of 900 men can get along on 900 to 1800 gpd under combat conditions for the first 3 days or so, but then it will need 4500 gpd relief, including water for drinking and cooking, and as soon as possible thereafter 15 gal/man or 13,500 gpd for the battalion. In case of emergency it is possible for the battalion to subsist on 450 gpd, which is asking the utmost of troops who are hyperstimulated from combat and dehydrated by perspiring, particularly in the tropics where at least some daily washing or bathing is more necessary than in the temperate zone. Water requirements thus start on the first day at a minimum of 900 gpd and an optimum of 2700 gpd based on the fact that, because of the circumstances of combat, less than 900 gal may reach the troops as channels of distribution are first set up. On the fourth day a minimum

of 2700 gpd must reach the battalion, but against a target of 4500 gpd. On the earliest day possible after the fourth day, unless either combat or water-supply problems intervene, a supply of 13,500 gpd should be available, which is equivalent to 9.5 gpm. For this a single source of production should suffice.

Phase II Water Requirements

Phase II (see Fig. 10) water requirements can be developed according to consumption schedules (Table 3) in a way similar to those discussed under Phase I but, in order to make allowance for paramilitary forces that will at times be cooperating in military or quasi-military tactical configuration, an additional 50 percent will be added to all schedules to define total potential requirements, even though they may occur less frequently than normal RTA requirements.

Each BCT (rs) base camp of 1000 men or so would require 15 gpd/ man for drinking, cooking, and bathing, with excavated latrines rather than waterborne sewage disposal. A 15,000-gpd total amounts to a supply of about 10 gpm, and probably a single source would suffice. Allowing for a periodic paramilitary demand, however, the total battalion-campsite demand becomes roughly 22,500 gpd and the production rate about 16 gpm, for which one producing source and one standby source might be desirable.

An RCT (rs) headquarters would include an additional 800 RTA officers and men beyond BCT (rs) strength, or at 15 gpd/man, a total of 27,000 gpd or 19 gpm. Allowing for paramilitary requirements the total requirement would be 41,000 gpd or 28 gpm, suggesting again the need for standby sources. Moreover, water points at both battalion and regimental base camps would have to be selected and monitored with some attention to locations of latrines and bathing facilities.

Companies operating on quick response out of BCT (rs) base camps, even if away from headquarters for as many as 3 days, would do well to carry water at least for the first day. A combat ration of 1 gpd/man would amount to 200 gal for a company, or 300 gal allowing for paramilitary requirements. For the second and third days, depending on circumstances, either additional quantities of 300 gpd could be transported in from BCT (rs) base camps, or manpack portable water-purification units could be used to exploit surface water or shallow dug wells. The additional hazard of vulnerability of both engineer water-squad personnel and purification equipment must also be taken into consideration. Once a man or the equipment have been lost, original logistical plans may no longer hold. Company and platoon water requirements on extended combat patrol or clandestine reconnaissance, meaning more than 3 days, have to be met in any way possible. Some water can be carried but not much. Manpack purification equipment can be carried but is unwieldy under the circumstances. Local sources need to be exploited, and this water must be disinfected on the spot by chemical means in circumstances where boiling is considered a non-secure procedure.

Phase III Water Requirements

Phase III (see Fig. 11) water requirements, in terms of consumption schedules used (Table 3), can be assessed starting with BCT base camps,

Fig. 10—Phase II. RTA Forces and Deployment
Scenario 1967–1970.

Boundary of AOR of headquarters unit RCT (rs) BCT (rs)

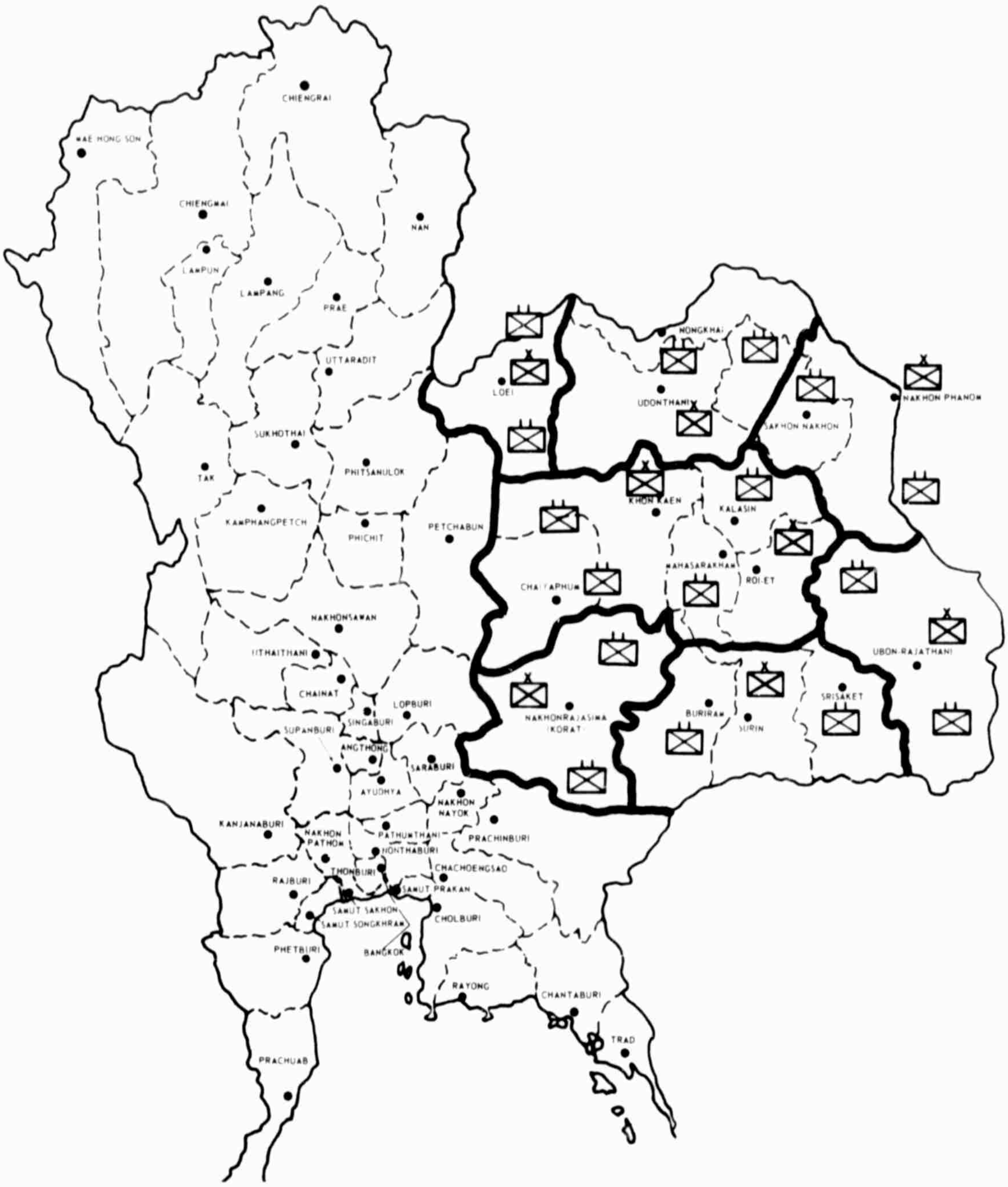

Fig. 11—Phase III, RTA Forces and Deployments
Scenario 1970–?

Boundary of AOR of headquarters unit RCT BCT

which with 1200 men requiring 15 gpd/man for drinking, washing, cooking, and bathing would need a supply of 18,000 gpd. With 50 percent added for potential paramilitary-force demand, the total requirement comes to 27,000 gpd or about 19 gpm, probably necessitating two sources. RCT headquarters base camps,

TABLE 4

Summary of Water Requirements at Each Level of Intensity of Insurgency

Unit		Mode	Ration, gpd/man	Total demand, gpd	Supply required	
Type	Strength				Gph	Gpm
		Phase I				
RCT	4500	Garrison	100	450,000	18,750	300
Battalion	900	Combat, austere	1	900	36	—
		Combat, relief	3	2,700	113	2
		Temporary camp	5	4,500	188	3
			15	13,500	563	9.5
		Phase II				
RCT (rs) HQ plus						
BCT (rs)	1800	Base camp	15	27,000	1,125	19
plus paramilitary	2400	Base camp	15	41,000	1,708	28
BCT (rs)	1000	Base camp	15	15,000	625	10
plus paramilitary	1500	Base camp	15	22,500	938	16
Company	200	Combat, austere	1	200	—	—
plus paramilitary	300	Combat, austere	1	300	13	—
Company	200	Combat, relief	3	600	25	—
plus paramilitary	300	Combat, relief	3	900	36	—
		Phase III				
RCT HQ plus BCT	2100	Base camp	15	31,500	1,313	22
plus paramilitary	3150	Base camp	15	47,250	1,967	33
BCT	1200	Base camp	15	18,000	750	13
plus paramilitary	1800	Base camp	15	27,000	1,125	19
RCT	4500	Combat, austere	1	4,500	188	3
plus paramilitary	6750	Combat, austere	1	6,750	280	5
RCT	4500	Combat, relief	3	13,500	563	9.5
plus paramilitary	6750	Combat, relief	3	20,250	827	14
BCT	1200	Combat, austere	1	1,200	50	—
plus paramilitary	1800	Combat, austere	1	1,800	75	1.25
BCT	1200	Combat, relief	3	3,600	150	2.5
plus paramilitary	1800	Combat, relief	3	5,400	225	3.75

each including one BCT, total 2100 men and would require 31,500 gpd. Adding the paramilitary 50 percent the requirement comes to 47,250 gpd or about 33 gpm, suggesting the desirability of exploiting two or three sources if possible. In both types of base camp, waterborne sewage disposal is not considered, and hence the usual problem of location of latrines with respect to water supply arises.

Battalions operating away from base camps would need 1 gpd/man in combat but otherwise 3 gpd/man, or 1200 and 3600 gpd respectively. Allowing for

support of paramilitary units these amounts become 1800 gpd in combat and 5400 gpd otherwise. Although, as in Phase II, individual companies can haul water initially into the field from base camps, battalion-support engineer platoons will in all probability need to develop water sources and establish water points after a day or two, moving their purification sets into the field with the units deployed. Although 5400 gpd works out to only 225 gph, this is sufficient to require at least batch-type equipment.

In the event an entire RCT moved into the field, each of the 4500 men would require 1 gpd in combat and 3 gpd otherwise, or 4500 gpd and 13,500 gpd respectively for the RCT. With 50 percent added for paramilitary support, requirements total 6750 gpd in combat and 20,250 otherwise. These in turn work out to 280 gph in combat and 827 gph for normal field ration. In the latter case the engineer support company would need to establish at least one major water point or several smaller ones.

Summary

Water requirements for RTA deployments at each level of intensity of insurgency are shown in Table 4.

WATER DEMAND AND AVAILABILITY

General

The information presented thus far consists of a discussion of groundwater and surface-water resources and their distribution, as well as a projection of forces and deployments based on an analysis of one of many possible

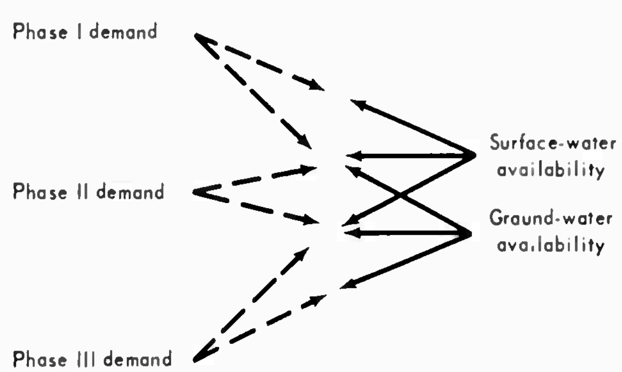

Fig. 12—Relations between Water Demand and Availability

scenarios outlining potential Communist insurgent activities in Northeast Thailand (Fig. 8). Deployed forces have predictable water requirements, and water resources possess a quality or degree of availability. This section compares availability with demand generated by water requirements as shown in Fig. 12.

"Availability" of either surface water or ground water is here used to mean the greatest quantity of water per unit time that can be taken from one

well or at one intake without impairing the military value of the water point. Availability is somewhat similar to safe yield but differs in that it considers the exigencies of military demand, the effects of overexploitation on equipment, and the nonpermanent character of the withdrawal.

"Demand" is used to mean the quantity of water per unit time that needs to be withdrawn from each well or intake in order to satisfy the military requirement.

It is the implied task of an engineer support unit to locate one or a number of water sources in such a way that, for each source, demand does not exceed availability.

Surface-water availability, in accordance with evaluations in the preceding discussion of the distribution of sources, could be expected to occur within the distances of a specific deployment in the Northeast shown in Table 1, Pt a.

Ground-water availability, as discussed previously, would be of two kinds, deep and shallow. Deep ground-water wells are spaced along major roads at irregular intervals of perhaps 2 to 15 km on the average, with some longer intervals of as much as 25 to 30 km. Although deep ground-water resources are very large, new wells cannot be drilled in support of rapid deployments. For support of headquarters base camps new drilling might be desirable as the most reliable water-supply source over a period of time. Otherwise, from most random points in the Northeast, deep ground-water wells will be accessible within roughly 50 km, with availability ranging from 2 to 100 gpm but averaging about 35 gpm.

Shallow ground-water availability probably approximates a dependable minimum of 10 gpm (600 gph) provided the well penetrates adequately into the ground-water body. Assuming only one existing well per village in the Northeast, the density of wells would be about one every 5 sq mi, or one well every 3 to 5 km in a random direction. New ones could be excavated quickly, particularly with power tools.

Phase I

The RTA RCTs now in garrison, each having a water requirement of approximately 450,000 gpd, are semipermanently established and do not face the problem of rapid location and determination of temporary water supply for the garrisons. Water supplies are at least adequate for these units at present, although engineer effort is needed to ensure repairs and maintenance. For the most part these garrisons exploit ground-water resources.

If a battalion were to deploy, it would require at least 900 gpd for the first 3 days, and then 2700 gpd by the fourth day. As soon as possible after this it should have 4500 gpd and ultimately, for a temporary camp, 13,500 gpd. These four requirements are equivalent to 37, 113, 188, and 563 gph. One water point would suffice in terms of water-purification-equipment-set production capability of 35 gpm, so that total demand rates would be met by a single water point and a single water source.

During the August–December season, surface water from flowing and nonflowing water bodies would be available to meet Phase I demands from single sources with haulage not greater than 10 km. The June–July availability of single sources of nonflowing water against these demands is unpredictable, but nonflowing single sources would be available with 5-km haulage.

Deep ground-water availability from single sources to meet Phase I demands could require haulage of 50 km, but shallow ground-water single-source availability would probably require no more than 3-km haulage from July to January; from February to June or July, assuming that one out of two wells is not deep enough, haulage would approximate 7 to 10 km.

Phase II

Base camps for RTA RCT (rs) headquarters plus one BCT (rs) plus a suitable paramilitary component would require 41,000 gpd of water, or 28 gpm. Base camps for the remaining BCT (rs) plus paramilitary forces would require 22,500 gpd, or 16 gpm. Although it would be desirable to drill for deep ground-water resources, several projected camps are close to flowing surface water that could be utilized during at least part of the year. For reasons of security ground-water wells would be preferable, and water-supply availability is normally one of the considerations in site selection.

To cover company operations together with paramilitary forces in Phase II, water requirements would be at least 300 gpd (13 gph) for the austere first 3 days and then 900 (37 gph) on the fourth day. Although these amounts could be hauled in over distances of 50 to 80 km from BCT (rs) base camps, a water squad with purification equipment could also, if absolutely necessary, go into the field with equipment to find these amounts available from single sources under the same conditions for both surface water and ground water as described in Phase I.

One 35-gpm water-purification-equipment set per RCT would seem not to be enough under Phase II circumstances of separate BCT base camps, and in all probability each BCT would need its own.

Phase III

A full-strength RTA RCT headquarters, plus one full-strength BCT, plus an appropriate paramilitary component, would require 47,250 gpd of water (33 gpm). A full-strength BCT base camp plus paramilitary component would require 27,000 gpd (19 gpm). As in the Phase II situation, surface water is available to many of these base-camp sites for at least part of the year, but ground water is preferable and camps should be located where drilling has shown an appropriate supply.

An entire RCT plus paramilitary component if deployed out of base camp would require an austere water ration of 6750 gpd (5 gpm) the first 3 days followed by 20,250 gpd (14 gpm). Haulage distances would approximate 10 to 50 km, or less than in Phase II operations, but, although carrying water from base camps into the field would undoubtedly be necessary or desirable the first day, a 35-gpm water unit should move into the area of operations and exploit local water resources. Under austere demand of 5 gpm, shallow ground-water resources could provide single-source availability, but the relief ration of 14 gpm might require two intakes, a difficult situation with only one purification set. Therefore either flowing surface water or a deep ground-water well should be utilized for adequate single-source availability. Otherwise additional purification equipment would be needed.

A full-strength BCT plus paramilitary component, as deployed into the

field, would require an austere water ration of at least 1800 gpd (75 gph; 1.3 gpm) for the first 3 days followed by 5400 gpd (225 gph; 3.8 gpm). Haulage distances would not necessarily be less than for an RCT as noted above, but the lesser requirement would mean less traffic into the operating area, for whatever that might be worth. But again, haulage all the way from base camps would be a less certain procedure and undoubtedly less secure than moving a 35-gpm water unit into the field and supplying the BCT directly. Single-source availability for shallow ground-water production would not be difficult to find, and either deep ground-water or flowing surface water resources would be an additional probability in many places during a large part of the year.

THE ROLE OF WATER IN RTA OPERATIONS

Logistical Summary

Table 5 presents an inventory of force levels, modes of operation, water requirements, probable mean maximum distances of water haulage from base camps, and the desirable number of 10-gpm field sources. Table 5 acquires additional significance in relation to the information in Table 1, "Water-Supply Availability," in terms of an analysis of distances from a random point in Northeast Thailand to 10-gpm water sources of various types. By and large the development of field water supplies, including purification for distribution, would seem to present no problems other than the usual ones of initial uncertainty until reconnaissance for water results in the determination of likely sites and sources. The absence of roads in many areas, as well as the deterioration of some existing ones in the rainy season, may present difficulties in hauling water from base camps. Caution would be advisable in utilizing existing village wells if such use is resented by the local civilians. New shallow wells or temporary sump pits are easily excavated using engineer equipment, causing only a momentary loss of time. Deep wells are somewhat different in that the people can be reminded that the well was installed by the RTG in the first place. In no case should it be necessary for local people to be deprived of water because of a military requirement. Plenty of water exists in places accessible to RTA engineers.

Equipment TOE

Most army TOEs have been developed over a period of time from the experience of conventional warfare, including the TOEs of the RTA. But within the specific context of engineer combat-support activity for the RTA as deployed in counterinsurgency operations in Northeast Thailand in the 1960's, there are reasons for changes in engineer TOEs in terms of additional water-purification equipment. One engineer company with one purification-equipment set cannot be expected in Phase III circumstances to support an RCT headquarters base camp including one BCT and at the same time support two other BCT base camps at distances of 50 km in different directions, and in addition be able to move into the field when and where necessary to support a BCT in action. Too much haulage of water from place to place would be required, specifically from RCT headquarters base camp to at least two other base camps and possibly to

TABLE 5

Summary of RTA Water Logistics in Counterinsurgency Operations

Force	Mode	Water requirement			Probable haulage from base camp, km	Number of 10-gpm sources needed	Remarks
		Gpd	Gph	Gpm			
					Phase I		
RCT	Garrison	450,000	18,750	300	—	several	Garrison sited with respect to water constraints
Bn	Combat, austere	900	36	—	100–150	1	—
Bn	Combat, relief	2,700	113	2	100–150	1	—
Bn	Camp	13,560	563	9.5	100–150	1	—
					Phase II		
RCT (rs) HQ + BCT (rs) + para[a]	Base camp	41,000	1,708	28	—	3	Base camp located near water supply
BCT (rs) + para[a]	Base camp	22,500	938	16	—	2	—
Co + para[a]	Combat, austere	300	13	—	40–80	1	—
Co + para[a]	Combat, relief	900	36	—	40–80	1	—
					Phase III		
RCT HQ + BCT + para[a]	Base camp	47,500	1,967	33	—	3	Base camp located near water supply
BCT + para[a]	Base camp	27,000	1,125	19	—	2	—
RCT	Combat, austere	6,750	280	5	50	1	—
RCT	Combat, relief	20,250	827	14	50	2	May need two intakes, extra pump, and hose
BCT	Combat, austere	1,800	75	1.5	50	1	—
BCT	Combat, relief	5,400	225	4	50	1	—

[a]Associated paramilitary forces.

two more field locations during actions. Augmentation of water-trailer TOE strength within the RCT, in view of the sparse road network in the Northeast, would not seem to be the answer. Added to this is the fact that two-wheeled water trailers exert high bearing pressures, which in the rainy season could prove impractical in soft ground. Finally, small ambushes of water-supply lines could reduce combat effectiveness out of all proportion to the insurgent effort expended. Adequate protection of water-supply routes could easily involve unacceptable expenditures of resources.

Considering the problem from the opposite viewpoint, the large potential availability of shallow ground-water resources throughout the Northeast suggests that additional water-purification equipment be added to TOEs, possibly enough for a ratio of one set to each battalion or BCT. These should probably be the 35-gpm batch-type portable Diatomite Water Purification Set No. 3, discussed as standard equipment for each engineer combat company. The adding of additional sets on this basis would mean a new TOE strength of one Set No. 3 to each engineer platoon.

Beyond this is the possible need for something smaller in the way of a manpack unit that would be available if needed to companies, battalions, and BCT in the field when operating in areas of difficult access. The 15-gpm Diatomite Water Purification Set No. 2 is a smaller portable batch set having four 500-gal fabric tanks. The entire unit plus its auxiliary equipment reduces to nine manpacks. The filter and pump unit alone weigh only 127 lb and without all four storage tanks even fewer men could carry this equipment. Such a unit could also supply an RCT in ideal conditions under 24-hr operation. Two of these units per regiment or RCT would mean the addition of two units to each engineer combat company TOE. Such units would represent an ideal hedge against the uncertainties of vehicle transport and accessibility on rapid deployments.

Water Reconnaissance and Engineer Intelligence

So far as can be determined the RTA does not carry on continuous and systematic reconnaissance of potential operation areas. If the RTA deploys into the field in counterinsurgency operations (or any other kind), they will need information on lines of communication; routes, structures, and materials; cross-country-movement suitability for wheeled and tracked vehicles; suitability of terrain for airborne operations; troop-related terrain factors such as cover, concealment, observation, fields of fire, and foot-movement rates; climatological factors; and water resources and availability. This is a rather elaborate list of most of the engineer-intelligence topics of the US Army, and of course such information will not be needed daily. From time to time, however, it can make the difference between success and failure in field operations and combat. It would be very useful to the RTA to have sets of detailed special-purpose maps of water-resources and well-survey information similar to maps used by the US Army. This would necessitate field reconnaissance and, in all probability, a cooperative terrain-analysis program with the RTG Department of Mineral Resources Ground Water Division. Modern armies generally do not

attempt to operate without this type of information. It is probable that Communist insurgents in the Northeast are making their own special-purpose maps as a prelude to operations.

Civil Action by the RTA

Probably the prime manpower resource of Thailand is the RTA, which also consumes a prime share of the national budget. If a way were found, in the midst of training and other duties, to deploy units of the RTA on civil missions of the "Peace Corps" type from existing garrisons in the Second Army Area comprising the 15 provinces of the Northeast, the results could be effective and significant. Areas of civil responsibility could be laid out and subdivided so that something on the order of squads could be deployed to individual villages. The task of these squads would be to help the village secure interim water supply by undertaking excavation of exploratory pits, trenches, or wells roughly 3 to 6 m deep at sites favorable for shallow ground-water resources.

In so doing, the RTA could (a) help resolve the problem of water supply; (b) gain favorable exposure in the Northeast as friend and helper to the civil population; (c) become familiar with water sources, terrain, and personalities in areas in which it might subsequently operate; and (d) serve to convert major national budgetary allocations to useful account during a time of no fighting, in the overall counterinsurgency effort in the Northeast. Such a program would not conflict with well-drilling operations, which are aimed at exploitation of deep ground-water resources for permanent production. Instead the RTA program envisioned here would aid in the excavation of shallow exploratory pits and the construction of wells producing from the largely unexploited shallow ground-water resources.

Undoubtedly such a program would incur added costs compared with normal garrison activity, but the type of effort discussed here could be of far-reaching importance as a counterinsurgent operation.

The attempt made here is not to spell out details of sizes of force allocations, heavy-equipment support, areas of responsibility, or lengths of time involved, but only to suggest that a small detachment of 6 to 10 men could accomplish much in 1 to 2 week s at the most in a village now short of good wells or water supply.

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Appendix A

PHYSICAL ENVIRONMENT OF NORTHEAST THAILAND

Figures

Tables

General

Northeast Thailand, the "Khorat Plateau" or "Korat Region," is a distinct geographic region encompassing all the eastward bulge of Thailand north of the 14th parallel. Although it is higher compared with the elevations of the Chao Phraya plain, it is in no sense a plateau but rather a shallow internally warped basin, both physiographically and structurally, surrounded by higher ground. The area included under these names has varied somewhat in references, from restriction to the interior basin to inclusion of all the bordering mountains. Current political definitions of the "Northeast" include all the 15 changwads that impinge on the interior basins. This definition includes an area of about 65,000 sq mi or one-third of Thailand's area and population.

Regardless of the actual boundaries the region is dominated by the basin's vast undulating plains, presenting a mosaic of sparse forest and padi, liberally sprinkled with small ponds, lakes, and marshy areas all of which are basically related to the hydrology of the region. The plains sections of the Northeast have a mean elevation ranging from 100 to 200 m (300 to 650 ft), being highest in the western and northern portions and lowest in the southeast around Ubon. The larger basin is actually broken into two low-gradient drainage basins by the northwestward-trending Phu Phan range, or line of hills. This hilly divide, geologically an anticlinorium, varies from heights of about 600 m (1950 ft) in the east to a low drainage divide in the west where it ends against a generally north-south-trending 500-m-high escarpment. Both basins are bordered by gently inward-dipping coarse-grained sedimentary rocks, which has led to considerable speculation about deep-artesian-water possibilities (DMJM,[9] p 20; LaMoreaux et al,[10] 1958, p 39; Doan,[11] 1963).

The much larger southern basin, that of the Lam Mun and its major tributary, the Lam Chi, drains an area of about 117,000 sq km and includes much of Northeast Thailand as a monotonous plain. Recurring episodes of alluvial deposition and uplift have produced at least three terrace levels (Moormann et al,[12] 1964, p 5) above the present river flood plains, the relative elevations and subsequent degradations of which markedly affect the local topography. These terraces, each with its characteristic level and gradient, slope downward, generally with decreasing dissection from the north and west to the southeast. Near Ubon the differences between the middle and lower terraces are only a few feet above the level of the alluvial flood plain.

Like most streams in the Northeast the Lam Mun drainage system cuts sharply into its flood plains with steep-bank heights in the dry season on the order of 8 m or more (27 ft). Stream gradients are, however, generally very low, increasing somewhat east of Phibun, where as an antecedent the Lam Mun breaches the low sandstone escarpment in a series of rapids to empty into the Mekong River. The very low relief, high seasonal rainfall, and single outlet of the basin cause extensive flooding during the rainy period, when the Lam Mun rises about 1 cm/day for 3 months beginning in May. Stream discharges vary

directly with this seasonal rainfall pattern (see section on climate), ranging at Ubon in a normal year from 13 to 3000 m^3/sec but with annual fluctuations (1951–1956) varying by a factor of 3.

The northern or Khong Basin (also referred to as the Sakhon Nakhon or Nam Songkhram Basin), believed by Charoen Phiancharoen (personal communication, 1966) to represent an ancient course of the Mekong River, is drained by a series of northward- or eastward-flowing small streams (the Lam Luange, the Nam Songkhram, and the Huai Nam Kam) into the Mekong River. The Mekong annually floods the adjacent lowlands of these tributaries during high-water periods, and the resulting current slowing and sedimentation have formed a series of small lakes and marshy ground along their channels. The Nam Song Khram flood plain in the northeastern portion of the basin is particularly swampy. This basin is also characterized by two large structurally formed shallow lakes that lie against the Phu Phan Divide. The terrace levels and seasonal flooding patterns of the Lam Mun Basin are reproduced in this northern basin on a somewhat reduced scale.

A discontinuous line of sandstone hills rises to a few hundred feet above the general basin level at the great bend of the Mekong, roughly parallel to the border fault.

The basin area is demarcated along the west and south by a continuous series of high hills and mountains, generally identified by name according to geologic structure and related physical appearance of the ranges. On the south and southeast the Phanom Dong Rek forms a steep outward-facing sandstone fault-line scarp with gentle dip slopes into the Lam Mun Basin. Elevations average 500 m (1650 ft) but extend up to more than 700 m (2300 ft) in places. In the southeast corner, where the Lam Mun itself rises, is the Sam Kamhaeng Range, a more irregular mountain block with elevations up to 1300 m (4300 ft). Along the western boundary are the high flat sandstone-capped hills and escarpments of the Dong Phraya Yen, the source of the Lam Chi. This range is backed and overlapped northward by the irregular metamorphic-based mountains of the Khao Petchabun Range, which includes peaks of 800 to 1300 m. The Mekong River generally marks the northern and eastern limits of the basin in Thailand, although the actual structural basin crosses the international boundary and ends in the mountains of Laos.

The water resources of the Northeast are the product of the complex interaction of a number of dependent, semidependent, and independent variables including the climate, geology, soils, and vegetation (Fig. A1). Through long cultural practices man has modified or influenced some of these variables; new efforts will cause further change.

Climate

The climate of Northeast Thailand is mapped by the Royal Meteorological Department as "Savanna Climate" and comes under the Koppen Classification as "Periodically Dry Savanna." Like that of the entire country it is monsoonal in character (Fig. A2). Cool dry air flowing from the Chinese mainland establishes the dry season, in which rainfall averages only 30 mm/month during 6 months of the year. Moisture-laden warm winds from the Indian Ocean establish the wet season. The geography of the area, characterized by generally

low elevation and relief surrounded by a ring of highlands, partly determines its climatic factors, particularly its water-supply potential.

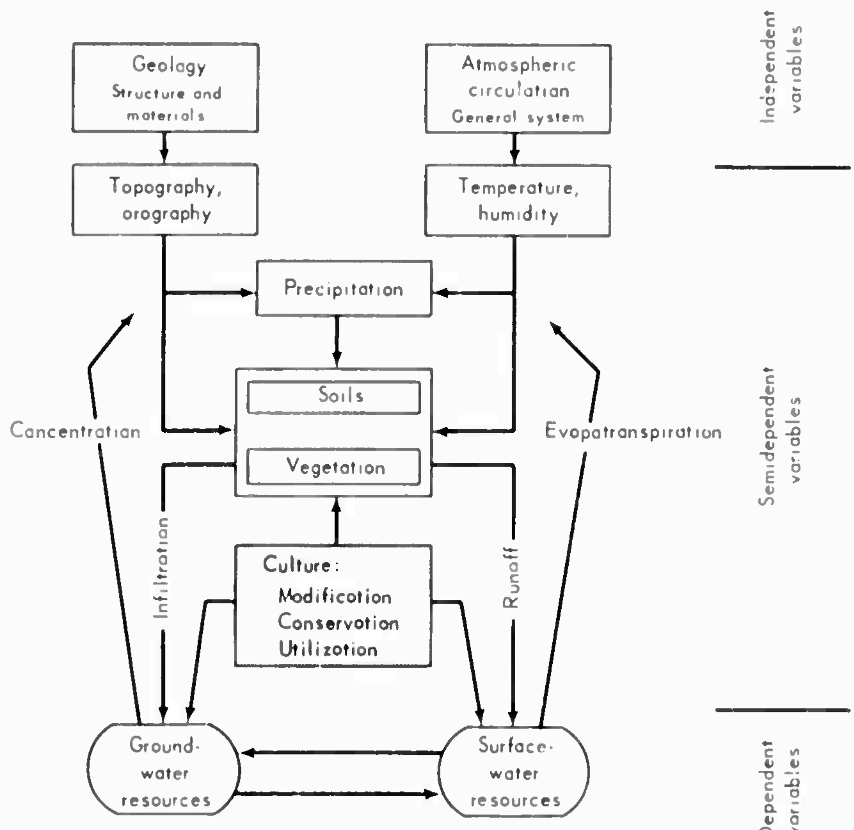


Fig. A1—Interrelations between the Environment and Water Resources

From the meteorological standpoint the seasons of the Northeast can be divided into the following four:

(1) The winter: cool weather, or northeast monsoon; from about November through February, the coolest months being December and January; precipitation is negligible for most of the period.

(2) The summer: hot, first transition, or retreating northeast monsoon; from March to about mid-May, April being the hottest month; precipitation is negligible during this and the winter season.

(3) The rainy season,or southwest monsoon: from early May through September; generally a period of increasing precipitation with maximums in September; frequently a dry period, the "early-season drought," occurs in June or July and usually continues for 15 to 20 days but may continue for 30 days or more.

(4) The warm-to-cool second transition, or retreating southwest monsoon: October; rainfall decreases sharply but the intensity of storms may be greatest during this season.

Fig. A2—Climatic Map of Northeast Thailand

The major climatic elements influencing water balance are precipitation, temperature, humidity, air movement, and radiation. These elements are therefore briefly summarized in the following paragraphs together with supporting tabular and map data.

The annual rainfall varies greatly over the Northeast from about 90 mm in the Khorat-Chaiyaphum area to more than 3900 mm during the last few years in the northeastern part of Nakhon Phanom Changwad. The heaviest rainfall usually occurs along the eastern and northern parts and along the extreme western parts of the entire Northeast (Fig. A3).[13] This variation is due principally to the orographic effect of the encircling hills and mountains. The mountainous western border, aligned so as to intercept the southwest-monsoon air streams, substantially reduces the rainfall immediately leeward of it. The average wet-season rainfall for the Chaiyaphum-Nakhonrajasima (Khorat) area is 920 mm; the central part of the plains gets 1100 mm; and the areas bordering the Mekong get 1450 mm (Kambu,[14] 1964). During the northeast monsoon, Northeast Thailand is in the lee of the Annamese Cordillera; however, where this mountain chain is closest, in the far northeastern corner near the channel of the Mekong, substantially more rain is received. During the rainy season of the southwest monsoon the air movements, and consequently rainfall, are pulsatory in nature. Bursts of rain alternate with rainless intervals of 3 or 4 days or more. Tropical storms and depressions reach the Northeast about two to three times a year during August, September, or, most frequently, October. Although beneficial as a supplementary supply of rainfall, they are not a dependable source; moreover, if they come in September in close succession extreme flooding may result.

As the nature of the rainfall is partly cyclonic, its intensity and frequency vary greatly. The minimum annual rainfall on record is about 41 percent lower than normal; the maximum is as high as 55 percent above normal. The US Bureau of Reclamation (1965)[15] reported that variations of total seasonal rainfall are not extreme. Their analyses of two Northeast stations having long-term records show that annual rainfall is infrequently less than 90 percent of normal and the probability of 2 consecutive years having less than 90 percent of normal is slight. Mean annual precipitation records of 119 stations in the Northeast are listed in Table A1, and the mean monthly variation is shown in 12 selected stations in Table A2.[16]

Although the earliest records began in 1906, and 32 stations began keeping records before 1910, they may be considered only as an approximation. Based on the work and observations of Sternstein[16] it is doubtful that any of the rainfall data (or probably any meteorological data) can be analyzed rigidly. Detailed conclusions based on such records must therefore be suspect. Sternstein found rainfall data collected by the Departments of Agriculture, Irrigation, and Forestry as well as those of the Tobacco Monopoly to be discontinuous and unreliable. Data of the Royal Meteorological Department were not suspect but were somewhat discontinuous. Of its 48 synoptic stations only 17 had kept records for 20 to 24 years, 22 for 10 to 20 years, and 9 for less than 10 years at the time of his study (1962). He concluded that only the 10-year records, 1951–1960, were suitable for analyses.

Temperatures during the rainy season average about 28°C (82.4°F), the mean maximum for all northern Thailand being about 31°C (87.8°F) and the

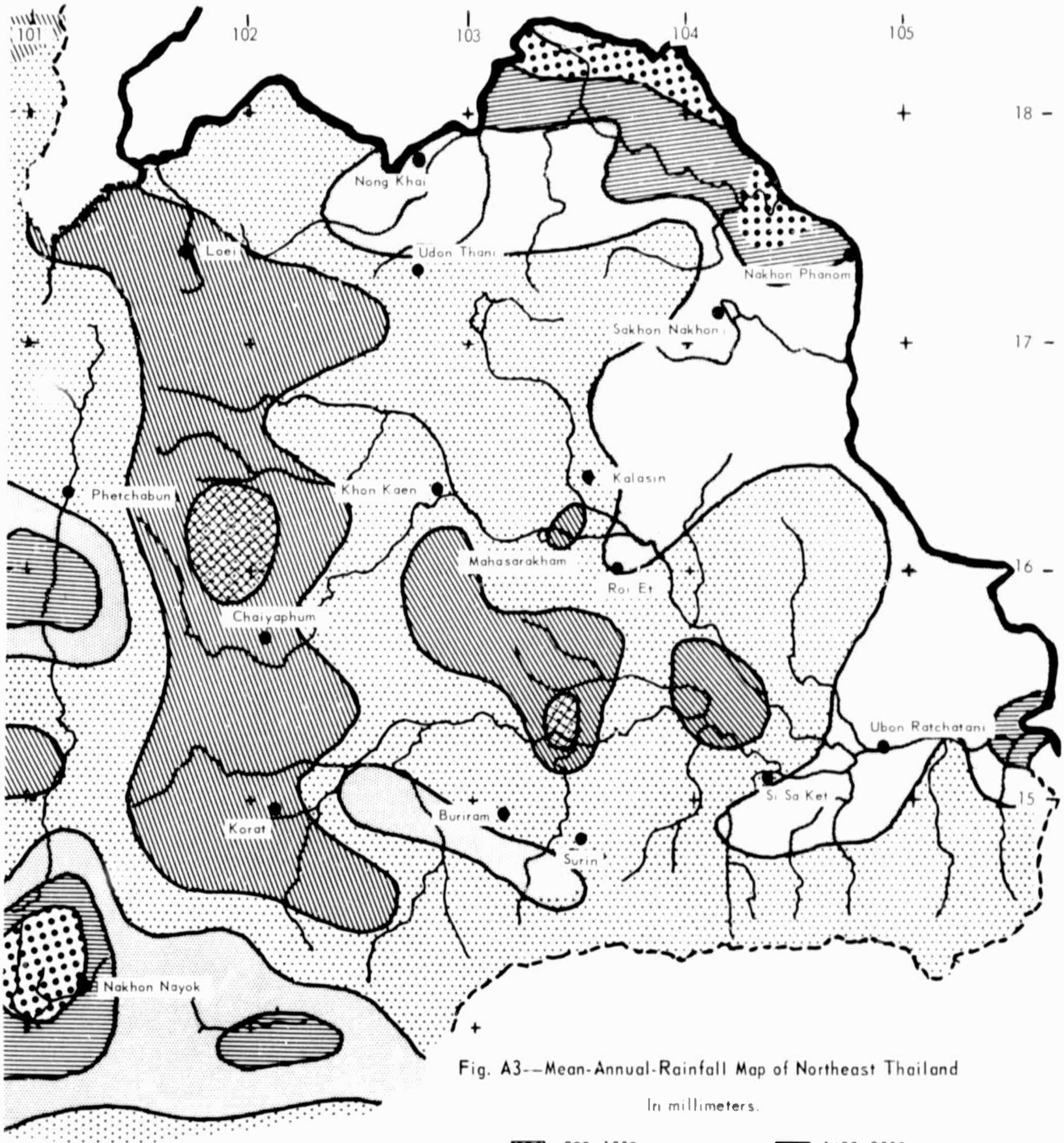


Fig. A3--Mean-Annual-Rainfall Map of Northeast Thailand

In millimeters.

- 800–1000 mm
- 1000–1200
- 1200–1400
- 1400–1600
- 1600–2000
- 2000–2400
- 2400–2800

From Royal Thai Survey Department.[13]

Place names spelled as on source map.

TABLE A1

Precipitation Records in Northeast Thailand[a]

Name of station[b]	Mean annual precipitation,[c] mm	Period of record	Name of station[b]	Mean annual precipitation,[c] mm	Period of record
Phon Phisai	1,572.2	1907–1963	Synoptic Roi Et	—	1960–1963
Tha Bor	1,599.5	1907–1963	Sisaket	1,373.4	1907–1963
Bung Khan	2,386.4	1907–1963	Khukhan	1,187.9	1917–1963
Sakon Nakhon	1,356.5	1907–1963	Kanthurarom	1,391.4	1922–1963
Sawang Dindan	1,680.8	1908–1963	Uthumphon Phisai	1,323.2	1922–1963
Phanna Nikom	1,377.0	1907–1963	Rasisalai	1,203.9	1922–1963
Burichaphoom	1,508.9	1955–1963	Kantharalak	1,471.5	1922–1963
Wanon Niwat	1,841.7	1907–1963	Loei	1,204.5	1907–1963
Synoptic Sakon Nakorn	—	1960–1963	Tha Li	1,219.9	1908–1963
Ubon Ratchathani	1,515.4	1910–1963	Dan Sai	1,155.3	1908–1963
Phibun Mangsahan	1,761.8	1912–1963	Wang Sapung	1,369.8	1907–1963
Amnat Charoen	1,580.9	1912–1963	Chiengkhan	1,205.9	1913–1963
Yasatorn	1,485.4	1912–1963	Surin	1,318.7	1907–1963
Khuang Nai	1,490.6	1922–1963	Sangkha	1,372.4	1907–1963
Warin Chamrab	1,429.3	1922–1963	Rutanaburi	1,205.4	1908–1963
Trakan Phodphon	1,491.7	1922–1963	Tha Toom	1,224.0	1922–1963
Kam Khuan Kaeu	1,409.0	1922–1963	Sri Khoraphum	1,258.1	1922–1963
Maha Chanachai	1,405.3	1922–1963	Prasat	—	1958–1963
Khong Chium	1,652.0	1922–1963	Synoptic Surin	—	1960–1963
Muang Samsib	1,506.1	1922–1963	Nong Khai	1,425.1	1916–1963
Det Udom	1,417.4	1914–1963	Khon Kaen	1,271.2	1907–1963
Baon Tarik	1,816.7	1922–1963	Manona Khiri	1,105.8	1914–1963
Leong Nok Tha	1,433.0	1952–1963	Phon	1,122.8	1915–1963
Chanuman	1,631.4	1922–1963	Chonnabot	1,127.2	1907–1963
Khemmarat	1,681.0	1921–1963	Phu Wieng	1,183.3	1909–1963
Synoptic Ubon	—	1960–1963	Nam Phong	1,229.8	1912–1963
Udon Thani	1,201.9	1907–1963	Chum Phue	1,089.8	1951–1963
Pen	1,415.3	1907–1963	Tha Kranon	—	1956–1963
Nong Han	1,245.1	1908–1963	Chiyaphum	1,058.7	1906–1963
Nong Buulampoo	1,201.9	1913–1963	Chaturat	1,036.7	1908–1963
Khumpavapi	1,064.8	1907–1963	Phu Khieo	1,031.6	1912–1963
Ban Phue	1,370.3	1915–1963	Bamnet Narong	1,026.2	1922–1963
Non Sang	—	1958–1963	Kaset Somboon	947.6	1922–1963
Synoptic Udon	—	1960–1963	Khon Sawan	1,137.2	1958–1963
Kulasin	1,374.4	1914–1963	Synoptic Chiyaphum	—	1960–1963
Yang Talat	1,290.0	1922–1963	Nakhon Phanom	2,213.4	1912–1963
Kamalasai	1,312.1	1946–1963	Thart Phanom	1,357.5	1909–1963
Sahatsakhan	1,411.6	1922–1963	Na Kae	1,450.5	1907–1963
Kuchi Narai	1,464.8	1922–1963	Makdahan	1,524.1	1907–1963
Nang Rong	1,274.2	1908–1963	Tha U-ten	2,121.3	1907–1963
Phat Thai Song	1,238.2	1921–1963	Si Songkram	1,943.9	1954–1963
Satuk	1,233.2	1951–1963	Ban Phang	2,560.8	1958–1963
Lam Plai Mat	1,385.1	1951–1963	Kam Cha Ei	—	1955–1963
Mahu Sarakham	1,227.8	1914–1963	Synoptic Nakhon Phanom	—	1960–1963
Borabue	1,248.0	1922–1963	Nakhon Ratchasimu	1,166.2	1906–1963
Vapee Pathum	1,299.5	1922–1963	Non Thai	1,007.4	1911–1963
Kuntharn Wichai	1,255.5	1922–1963	Non Soong	1,131.7	1915–1963
Kosoom Phisai	1,111.1	1922–1963	Bua Yai	1,191.6	1922–1963
Phayakkhaphum Phisai	1,272.0	1922–1963	Phi Mai	1,262.2	1909–1963
Kamalasai	1,312.1	1922–1963	Sung Noen	1,136.7	1911–1963
Roi Et	1,384.9	1907–1963	Si Khiu	1,094.8	1914–1963
Kaset Wisai	1,315.6	1916–1963	Dan Khan Thot	1,017.1	1914–1963
Suwanhaphum	1,560.4	1915–1963	Chok Chai	1,027.4	1911–1963
Thawatburi	1,351.4	1922–1963	Pak Thong Chai	1,106.2	1911–1963
Ard Samat	1,338.7	1922–1963	Khon Buri	1,086.6	1910–1963
Phan Thong	1,321.5	1922–1963	Chakkarat	1,197.2	1922–1963
Chataraphak Phiman	1,249.7	1922–1963	Bu Pai	—	1955–1963
Phanom Prai	1,406.2	1922–1963	Kong	—	1956–1963
Selaphum	1,328.9	1916–1963	Buriram	1,252.9	1906–1953
			Prakhon Chai	1,363.4	1921–1963

[a]From US Bureau of Reclamation, 1965.[15]
[b]Place names spelled as in source document.
[c]Mean from the beginning of the period of record to 1960.

TABLE A2

Mean Monthly and Mean Annual Rainfall[a]

(In millimeters)

Station[b]	Period	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Phetchabun	1931–1960	9.3	25.6	46.5	78.0	160.3	182.8	195.6	201.9	277.0	95.0	19.1	0.0	1291.1
Loei	1931–1960	7.5	19.3	35.8	90.5	175.1	173.1	134.5	211.3	227.3	110.3	20.1	1.9	1206.7
Udon Thani	1931–1960	7.9	19.6	40.2	96.6	223.2	215.8	199.8	248.0	266.6	88.5	17.4	4.3	1427.9
Nakhon Phanom	1931–1960	4.9	13.6	21.7	81.3	216.0	384.2	474.2	534.1	358.1	64.3	6.7	3.1	2162.2
Sakon Nakhon	1931–1960	7.2	19.9	54.5	83.5	268.2	260.4	305.0	331.0	379.6	70.0	12.6	1.2	1793.1
Mukdahan	1932–1960	3.2	11.0	[illegible]	83.5	212.5	217.7	246.2	269.2	290.7	50.4	5.6	2.2	1437.2
Khon Kaen	1931–1960	6.0	19.7	29.0	72.9	184.9	164.5	162.8	170.0	277.0	91.1	8.6	2.6	1189.1
Roi Et	1931–1960	2.0	24.5	35.1	91.0	198.7	180.5	212.4	246.0	325.1	73.7	13.0	2.8	1112.2
Chaiyaphum	1931–1960	2.4	14.3	44.3	72.7	147.9	136.9	121.8	166.5	247.0	85.7	13.7	0.9	1054.1
Ubon Ratchathani	1931–1960	6.2	10.3	39.9	71.7	172.1	204.8	250.6	313.0	309.9	131.9	26.2	1.9	1538.5
Surin	1931–1960	2.2	11.9	43.2	71.3	171.3	168.2	191.8	223.6	268.2	156.6	29.2	0.6	1337.9
Nakhon Rachasima	1931–1960	7.3	33.3	45.2	82.9	156.7	111.2	132.0	138.8	243.6	171.0	36.6	2.9	1161.5
Maximum		9.3	33.3	54.5	96.6	268.2	384.2	474.2	534.1	379.6	171.0	36.6	4.3	2162.2
Mean		5.5	18.5	40.0	81.3	190.6	200.0	218.9	254.5	264.2	99.0	17.4	2.0	1391.9
Minimum		2.0	10.3	21.7	71.3	156.7	111.2	121.8	166.5	227.3	50.4	5.6	0.0	1054.1

[a]From Molagool,[16] 1962.

[b]Place names spelled as in source document.

mean minimum about 23°C (73.4°F). During October, along with increasing north-to-easterly winds and rapidly decreasing rainfall, the average temperatures decrease to about 26.5°C (79.7°F). From November to February cool dry air covers all the Northeast. Rainfall is practically nil, and average temperatures are about 24°C (75.2°F). The period March–April is one of rapidly rising temperatures, April being the hottest month of the year. The occasional rainfall is associated with late-afternoon or evening thunderstorms. Average temperatures approximate 29°C (84.2°F). Mean monthly temperatures for 12 stations in the Northeast (Table A3) vary from 27.5°C in December to 29.7°C in March or 7.2°C with the difference between mean maxima and mean minima being only 10°C. Figure A4 shows annual average temperatures of parts of the area. Mean differences between individual stations vary by scarcely more than 1°C for most months. Differences between absolute maxima and absolute minima show variations up to almost 36°C, the highest values being during the cold season.

Relative humidities are generally low in the northeast monsoon season (Table A4), February and March being the lowest with about 61 percent. Humidity increases in the hot season and with the onset of the southwest monsoon. Monthly mean relative humidities rise gradually, reaching a peak of about 82 percent in September, after which they drop sharply.

Recorded wind velocities are generally quite low throughout the Northeast (Fig. A5). Mean 4-year records (Table A5) show Roi-Et to be the windiest station. However, means for all stations reach only 1.5 on the Beaufort scale (5 mph) and then only for the month of December. These low velocities have a negligible effect on the overall evaporation rate, but they may have a positive influence on evaporation-retardant films (Meyer,[18] 1965; LaMer and Healy,[19] 1965).

Cloudiness follows a seasonal pattern. The wet season brings on extensive cloudiness and a general decrease in solar radiation (Table A6). Clear skies are a rarity except during the periods of early-season droughts. During the day in the dry-season period, November–March, clouds are rare; those that do occur are generally high and mostly over the mountainous borders. Hence there is very little natural atmospheric impedance of solar radiation when such impedance would be most beneficial. The effect of the annual dry-season haze caused by the burning of padi stubble, woodlands, underbrush, and clearing operations has not been assessed but in terms of total radiation may be of minor significance.

Geology

The earth's history comprises sequences of competing and reinforcing geologic processes, the present landscape representing only one point in time in a dynamic continuum. The "geology" of an area is a major independent variable ultimately controlling or influencing almost all other environmental factors. It is crucial to the determination of ground-water resources.

The lithology of the rocks together with the geochemical and structural forces that have acted on them largely controls their relative permeability and porosity (Table A7[20]), which in turn determines their potential as aquifers, aquicludes, or aquitards. An aquifer's stratigraphic relation to nonaquifers,

TABLE A3

Mean Monthly Air Temperature[a]

(In degrees Centigrade)

Station[b]	Period	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Phetchabun	1930–1960	23.1	26.0	28.3	30.1	29.3	28.2	27.5	27.2	27.4	26.8	25.1	22.7
Loei	1954–1960	20.4	26.8	25.2	27.5	28.7	28.1	27.5	27.1	26.8	25.4	23.3	20.8
Udon Thani	1937–1960	22.5	24.9	27.9	29.8	29.4	29.0	28.4	27.9	27.8	26.8	25.1	22.3
Nakhon Phanom	1952–1960	21.5	23.7	27.0	29.1	28.6	28.2	27.5	27.2	27.0	25.8	23.9	21.5
Sakon Nakhon	1947–1960	21.7	24.0	27.5	29.3	28.8	28.6	27.9	27.7	27.3	26.2	23.8	21.8
Mukdahan	1953–1960	21.7	24.6	28.1	29.8	29.5	28.7	28.0	27.8	27.5	26.1	24.3	21.9
Khon Kaen	1948–1960	23.1	25.8	28.9	30.0	29.7	29.0	28.3	28.1	27.7	26.8	24.9	22.8
Roi Et	1943–1960	23.6	25.8	28.8	30.1	29.7	29.0	28.4	28.1	26.9	26.5	25.0	22.9
Chaiyaphum	1956–1960	24.0	25.9	28.8	30.3	30.4	28.9	27.0	27.5	27.0	26.4	25.2	23.5
Ubon Ratchathani	1943–1960	24.0	26.1	28.6	29.8	29.2	28.5	27.9	27.8	27.3	26.5	25.2	23.6
Surin	1948–1960	24.0	26.6	29.2	30.2	29.7	29.0	27.8	28.2	27.8	26.8	25.2	23.5
Nakhon Ratchasima	1937–1960	23.8	26.8	29.0	29.9	29.3	28.7	28.3	28.1	27.5	26.5	25.1	23.0
Maximum		24.0	26.8	29.2	30.3	30.4	29.0	28.4	28.2	27.8	26.8	25.2	23.6
Mean		22.8	25.6	28.1	29.7	29.4	28.7	27.9	27.7	27.3	26.4	24.7	22.5
Minimum		20.4	23.7	25.2	27.5	28.7	28.1	27.5	27.1	26.8	25.4	23.3	20.8

[a]From Molagool,[16] 1962.

[b]Place names spelled as in source document.

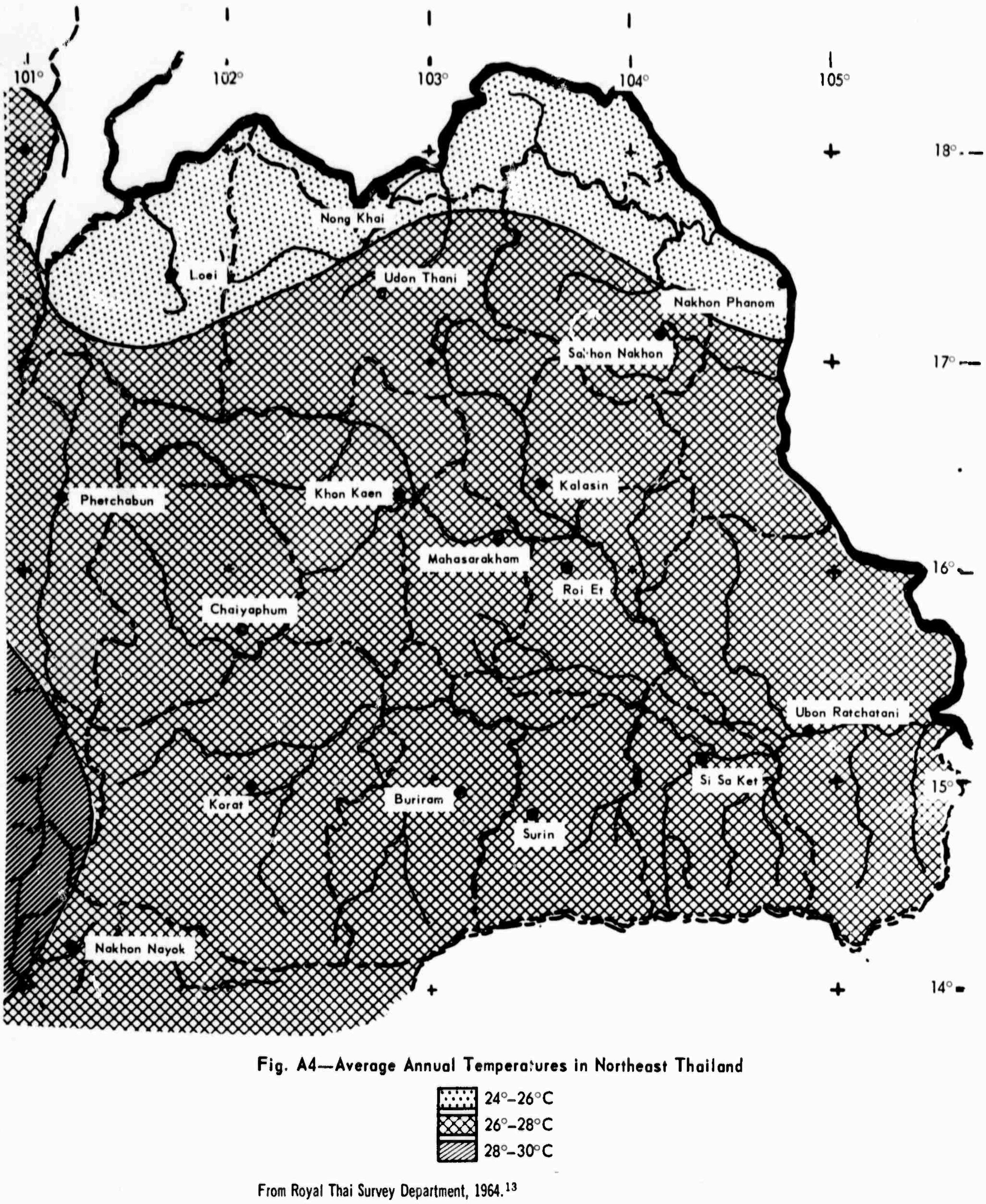


Fig. A4—Average Annual Temperatures in Northeast Thailand

From Royal Thai Survey Department, 1964.[13]

Place names spelled as on source map.

TABLE A4

Mean Monthly Relative Humidity[a]

(In percent)

Stations[b]	Period	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Phetchabun	1951–1955	71.1	65.2	64.6	65.0	76.3	82.1	82.4	86.0	85.7	81.7	76.4	66.5	74.4
Loei	1954–1955	67.2	63.0	58.6	62.8	76.0	79.7	75.3	82.4	82.6	76.0	71.4	67.0	71.8
Udon Thani	1937–1955	68.5	66.6	63.1	68.2	78.0	80.7	81.0	82.4	83.3	77.3	64.1	71.0	74.5
Nakhon Phanom	1953–1955	70.3	68.9	63.2	68.1	78.5	84.4	83.8	87.0	85.5	75.2	70.2	69.0	75.3
Sakon Nakhon	1948–1955	61.5	61.3	53.5	65.4	76.5	78.9	79.9	82.7	82.6	75.2	70.4	65.8	71.1
Mukdahan	1943–1955	62.3	60.4	56.9	61.4	70.6	76.4	76.5	78.4	79.5	71.0	67.6	64.7	68.8
Khon Kaen	1947–1955	64.3	63.0	60.0	63.5	72.8	75.3	77.6	80.1	81.6	76.7	71.4	66.3	71.1
Roi Et	1943–1955	61.3	60.9	60.0	69.3	73.0	75.9	74.3	79.0	80.8	73.2	63.7	62.7	69.1
Ubon Ratchathani	1943–1955	62.4	59.9	67.5	64.9	75.2	83.4	78.3	77.8	81.0	74.0	69.8	66.1	71.7
Surin	1943–1955	59.9	58.9	57.9	64.7	73.0	75.8	76.1	78.5	80.6	75.5	70.9	55.3	69.8
Nakhon Ratchasima	1937–1955	65.9	63.9	64.3	69.6	77.5	76.4	75.3	76.9	81.9	72.7	75.0	70.2	73.0
Maximum		71.1	68.9	67.5	69.6	78.5	84.4	83.8	87.0	85.7	81.7	76.4	71.0	74.4
Mean		65.0	62.9	60.9	65.7	75.2	79.0	78.2	81.0	82.3	76.0	71.0	65.9	71.9
Minimum		59.9	58.9	53.5	61.4	73.0	75.3	74.3	76.9	79.5	71.0	63.7	55.3	68.8

[a]From Molagool,[16] 1962.
[b]Place names spelled as in source document.

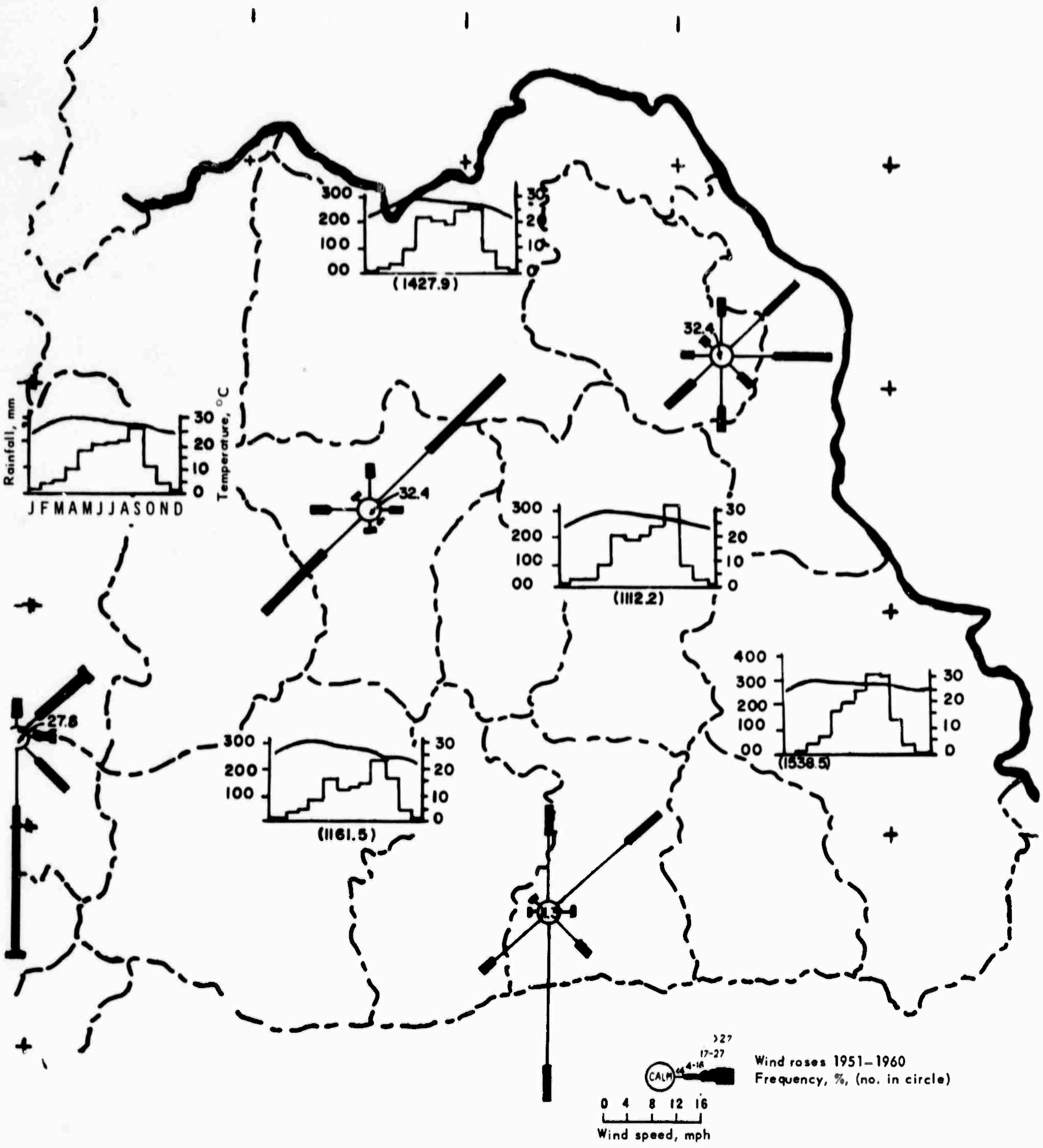


Fig. A5—Wind Velocity, Monthly Rainfall, and Temperature Variations, Selected Stations in Northeast Thailand

From Royal Thai Survey Department, 1964.[13]

Line curves, monthly temperature; stepped curves, monthly rainfall; (1112.2), annual rainfall; 1931–1960

TABLE A5

Mean Monthly Wind Velocity[a]

(In Beaufort scale values)

Stations[b]	Period	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Phetchabun	1950–1954	0.7	0.8	1.0	1.1	1.0	1.2	1.2	1.1	0.9	1.0	1.0	1.4
Loei	1954–1956	1.3	1.2	1.3	1.2	1.2	1.1	1.3	1.0	1.3	1.1	1.2	1.1
Udon Thani	1950–1954	1.0	1.1	1.2	1.1	1.0	1.7	1.8	1.2	1.1	1.0	0.9	1.0
Nakhon Phanom	1952–1956	1.8	1.2	1.5	1.0	1.0	0.8	1.0	0.9	0.8	1.2	1.3	1.5
Sakon Nakhon	1950–1954	1.1	1.3	1.1	1.1	0.8	0.9	1.0	1.1	0.9	1.1	1.0	1.2
Mukdahan	1950–1954	1.5	1.6	1.4	1.3	1.2	1.4	1.3	1.2	0.9	1.5	1.7	2.3
Khon Kaen	1950–1954	1.1	1.1	1.2	1.2	1.2	1.3	1.3	1.3	0.9	1.1	1.2	1.3
Roi Et	1950–1954	1.5	1.7	1.8	2.0	1.7	2.0	1.9	1.9	1.4	1.6	1.9	1.9
Ubon Ratchathani	1950–1954	0.9	1.0	1.0	1.0	0.9	1.2	1.0	1.2	0.9	1.2	1.3	1.9
Surin	1950–1954	1.1	1.2	1.2	1.3	1.2	1.3	1.2	1.3	1.1	1.2	1.3	1.5
Nakhon Ratchasima	1950–1954	0.7	0.9	0.9	1.0	0.9	1.4	1.4	1.4	0.8	1.0	1.0	1.0
Maximum		1.8	1.7	1.8	2.0	1.7	2.0	1.9	1.9	1.4	1.6	1.9	2.3
Mean		1.2	1.2	1.2	1.2	1.1	1.3	1.3	1.2	1.0	1.2	1.3	1.5
Minimum		0.7	0.8	1.0	1.0	0.9	0.8	1.0	0.9	0.8	1.0	1.0	1.0

[a]From Molagool,[16] 1962.

[b]Place names spelled as in source document.

TABLE A6

Mean Monthly Solar Radiation at Nakhon Phanom

Month	Langleys/day	Month	Langleys/day
Jan	426.05	Jul	342.63
Feb	427.81	Aug	505.27
Mar	450.61	Sep	348.26
Apr	514.92	Oct	445.00
May	498.07	Nov	439.17
Jun	351.96	Dec	407.17

TABLE A7

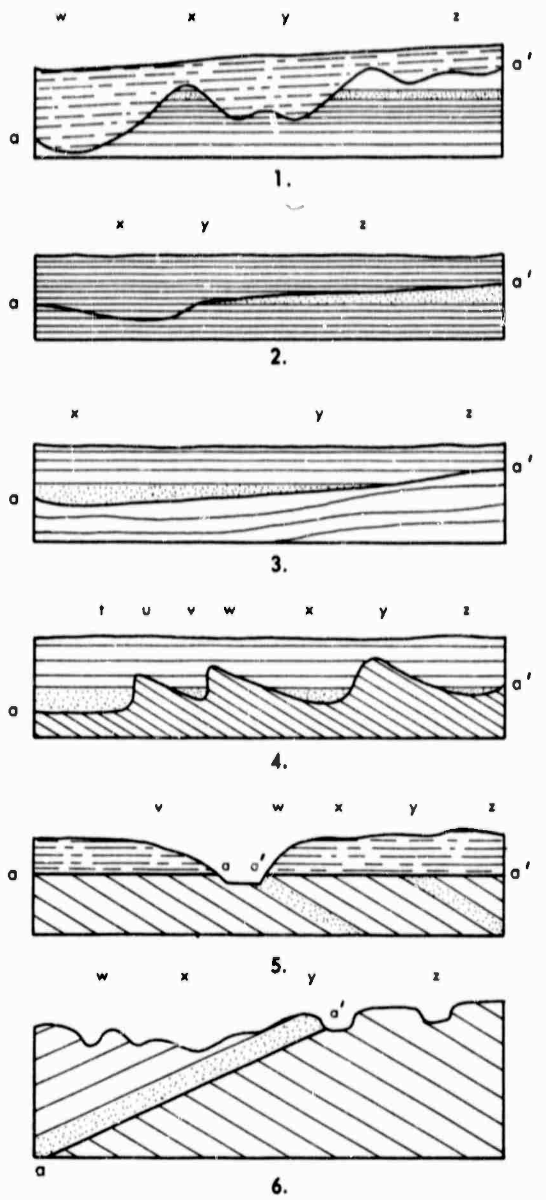
Water-Bearing Properties of Common Rocks and Soils[a]

Permeability[b]	Porosity[b]
Highest	Highest
Well-sorted gravel	Soft clay
Porous basalt	Silt
Cavernous limestone	Tuff
Well-sorted sand	Well-sorted sand
Poorly sorted sand and gravel	Poorly sorted sand and gravel
Sandstone	Gravel
Fractured crystalline rock	Sandstone
Silt and tuff	Porous basalt
Clay	Cavernous limestone
Dense crystalline rock	Fractured crystalline rock
	Dense crystalline rock

[a]Based on Davis and DeWiest,[20] 1966.
[b]Arranged in order from highest to lowest.

its gross petrology, and its structural and erosional history, together with its areal location with respect to recharge, determines the amount and quality of the water it may contain. As these relations, even in simple form, may be diverse (Fig. A6[21]) and complex within relatively short distances, a thorough understanding of a region's geology is basic to determining its water potential.

Northeast Thailand occupies the western part of a geologically stable area that has undergone little large-scale tectonic disturbance since the Paleozoic[22] Era. (Geologic ages referred to herein are shown in Table A8.[22]) Although orogenic zones surround it, this stable block shows only minor flexures, uplift, and intrusive action. The oldest rocks are mid- to late-Paleozoic sediments: the Silurian to Carboniferous Kanchanaburi series of shales and sandstones and the Permian Rat Buri limestone. All these formations were complexly folded and in part metamorphosed before being substantially eroded to yield a more or less rough surface. In early Mesozoic time (Triassic Period) this surface began to subside at variable rates and through various climatic regimes but dominantly under conditions of continental deposition of sands, gravel, silts, and clay, building great thicknesses of sandstones, conglomerates, siltstones, and shales that are collectively a part of the Khorat group or series.



1. Region undeformed; lower (water-bearing) series of rocks eroded into a hilly terrane before upper series deposited; aquifer may be extremely discontinuous

2. Region undeformed; lower series eroded nearly to a plain; aquifer more continuous than in 1

3. Lower series of rocks warped gently before upper (water-bearing) series deposited; aquifer may be fairly continuous; locally, as at either end of section, the beds of the two series may be strictly parallel

4. Lower series strongly tilted and eroded into a hilly terrane before upper (water-bearing) series deposited; aquifer may be most discontinuous

5. Lower (water-bearing) series strongly tilted and then beveled before upper series deposited; recharge opportunity variable, as aquifer may not crop out

6. Lower series strongly tilted clockwise and beveled; upper (water-bearing) series deposited; region then tilted counterclockwise and eroded to moderate relief

Fig. A6—Some Typical Aquifer Relations to Simple Structural and Erosional Modifications of Sedimentary Rocks

Stippled areas: aquifers; a a', old erosional surface; t, u, v, w, x, y, z, well sites yielding different results.

Based on Geological Survey Water Supply Paper 489.[21]

TABLE A8

Geologic Time Scale[a]

Era	Period or system	Epoch or series	Approximate time before present, millions of years	Approximate length, millions of years
Cenozoic	Quaternary	Recent Pleistocene	0–1	1
	Tertiary	Pliocene	1–12	11
		Miocene	12–28	16
		Oligocene	28–40	12
		Eocene Paleocene	40–60	20
Mesozoic	Cretaceous	Upper (Late) Lower (Early)	60–130	70
	Jurassic	Upper (Late) Middle (Middle) Lower (Early)	130–155	25
	Triassic	Upper (Late) Middle (Middle) Lower (Early)	155–185	30
	Permian	Provincial series recognized in west Texas	185–210	25
Paleozoic	Carboniferous systems: Pennsylvanian	No formal subdivisions	210–235	25
	Carboniferous systems: Mississippian	No formal subdivisions	235–265	30
	Devonian	Upper (Late) Middle (Middle) Lower (Early)	265–320	55
	Silurian	Upper (Late) Middle (Middle) Lower (Early)	320–360	40
	Ordovician	Upper (Late) Middle (Middle) Lower (Early)	360–440	80
	Cambrian	Upper (Late) Middle (Middle) Lower (Early)	440–520	80
Proterozoic	Pre-Cambrian	Upper pre-Cambrian rocks (Keweenawan and other provincial series) Middle pre-Cambrian rocks (Huronian and other provincial series) Lower pre-Cambrian rocks (provincial series)	520–2100+	1600+

[a]Based on US Geological Survey, 1954.[22]

Compaction has indurated these rocks and has consequently limited their hydraulic transmissibility and aquifer potential.

Current thinking (Haworth et al,[23] 1966) is that toward the end of the Mesozoic Period, and perhaps extending into the early Cenozoic, tectonic activity uplifted and faulted (the Dangrek scarp) the western and southern margins of the lower Khorat series concurrent with the gentle warping of the Phu Phan Range into a series of parallel anticlinal and synclinal folds across the northern part of the primary basin. Deposition continued perhaps intermittently during this period with an intervening period of erosion so that the two structural basins thus formed began to be filled by marine sedimentation of silts and clays (upper Khorat series). In areas remote from seawater exchange, thick beds of gypsum, anhydrite, and rock salt were deposited (the Salt formation) in these basins. A summary of possible origins of the salt deposits by Suwit Watthanachan[23] (1964) suggests that domal uplifts along the crests of anticlinal folds of the Phu Phan Range are related to salt domes.

The net effect of this tectonic sequence is that Northeast Thailand's principal rock formations, the Khorat sedimentary series, generally dip toward the central parts of the existing basins at low angles of perhaps 5 to 10 deg, accounting for the artesian conditions of most wells drilled into them.

In late Mesozoic and early Cenozoic time igneous activity began along the margins of the Northeast basin, perhaps concurrent with tectonic activity along lines of weakness. The western border includes areas of younger granites and granodiorites intruding the Paleozoic rocks that in some places are overlain unconformably by the Khorat group. Basalt flows and dikes intrude the Khorat series between the Lam Mun and the Dongrek escarpment, and basalt also occurs in an extensive area northeast of Lopburi. Andesites and rhyolite porphyries intrude all rocks along the western borders including the basalts.

A brief description of the geologic units together with their water-bearing characteristics as defined by recent work (Haworth <u>et al</u>,[23] 1966) is included in Table A9. Post-Khorat-series geologic history has <u>not</u> been well defined or studied extensively but includes a series of uplifts and consequent erosional depositional surfaces (terraces) extending into the Quaternary as minor structural developments producing and defining the present landforms. As is commonly the case, the interface between rock "geology" and "pedology" becomes a gap, a "no-man's-land," between consolidated rocks and the surface soils. This area of investigation of "unconsolidated rocks" belongs within a specialized field of geology, geomorphology, but no known substantive work has been accomplished in the Northeast by geomorphologists.

The early work by soils scientists such as Pendleton[2] (1962, p 71) assumed that almost all unconsolidated materials of the Northeast not in floodplains were developed on weathered rocks of the Khorat series. LaMoreaux[10] (1958, p 13) postulated uplift in three stages and recognized at least three surfaces of peneplanation. The oldest formed in Cretaceous time and is now the crest of the Phu Phan range; one at about 180-m present elevation formed in Miocene or Pliocene time; a third at 140-m elevation, in Pleistocene time, with possibly a fourth at about 75-m elevation. The mapped unconsolidated deposits in the geological sense are restricted to the alluvial areas along the principal rivers of the Northeast, but their actual extent and thickness are not well known. As identified, most of these deposits are less than 50 ft thick, locally becoming

TABLE A9

Generalized Geologic Table of Rocks of Northeastern Thailand and Their Water-Bearing Characteristics[a]

Era	Period	Rock unit	Thickness	Description	Water-bearing characteristics
Cenozoic	Quaternary	Alluvium and terrace deposits	—	Alluvial sand and gravel with numerous beds and lenses especially along the courses of the Chi and Mun Rivers	The average yield is about 100 gpm, but up to 300 to 500 gpm especially in the Nakhon Phanom area; water quality is variable due to local contamination from underlying formations
Cenozoic	Tertiary	Andesite and rhyolite porphyry	—	Stocks and dikes in andesite porphyry cut by younger rhyolite porphyry dikes and flows; in places intrudes or overlies basalt or diorite	A well yielding 180 gpm is reported from Kokesamrong; most wells penetrate cracks or joints of these rocks yielding enough water for domestic uses
Cenozoic	Tertiary	Basalt	—	Basalt in flows, dikes, and plugs; mostly dense, locally scoriaceous to amygdaloidal; intrudes and overlies the Khorat Series	Wells may yield up to 100 gpm but most yields are from a few to 50 gpm; many wells are dry
Cenozoic	Tertiary	Diorite and quartz diorite	—	Dikes, stocks, and small batholiths; intrudes Khorat Series and older rocks	Most drilled wells are dry; some yield up to 5 gpm
Mesozoic	Cretaceous and younger	Khorat Series (Group): Unnamed salt formation	610 m (2003+ ft)	Pale-red to reddish-brown sandstone, sandy shale, and siltstone; gypsum and anhydrite in beds up to 50 ft thick and rock salt up to more than 800 ft	Wells average 20 to 30 gpm in joints, cracks, and bedding planes; many wells yield more than 100 gpm; quality is generally good except in low lying areas saturated with salt (30% of area); most wells are nonflowing artesian
Mesozoic	Cretaceous	Khorat Series (Group): Khok Kruat	709 m (2325 ft)	Grayish-red to reddish-brown sandstones, siltstones, and shales with greenish-gray mottling, streaks, and spots; gypsum occurs as thin beds, scattered crystals, and in joints and cracks in the upper part	Wells average about 20 gpm mostly from sandy shale and conglomerate; some yield over 50 gpm; quality is variable, iron and sulfate is high in about 50% of wells; most wells are nonflowing artesian

TABLE A9 (continued)

Era	Period		Rock unit	Thickness	Description	Water-bearing characteristics
Mesozoic	Jurassic to Cretaceous (?)	Khorat Series (Group)	Phu Phan	82–183 m (270–600 ft)	Yellowish-gray to grayish-pink, pale-orange and pale-red, massive, thick-bedded and cross-bedded sandstone and conglomeratic sandstone; includes thin beds of grayish-red to grayish-red-purple sandy shales and siltstone and thin beds of calcareous conglomerate; the top is marked by a very thick-bedded unit of conglomeratic sandstone and conglomerate	Yields from 2 to 80 gpm from joints, cracks, bedding planes, conglomerate, and shaly zones; generally of good quality, locally high in iron content; some areas contain poor-quality connate water; most wells are nonflowing artesian; several have heads up to 36 ft above ground surface
	Jurassic (?)		Phra Wihan	460–856 m (1503–2807 ft)	Grayish-red to olive-gray to white massive sandstone with dark-reddish-brown micaceous shale and grayish-red micaceous siltstone; in part cross-bedded or thick-bedded with numerous joints	Water-bearing characteristics about the same as the Phu Phan but quality slightly better; most wells are nonflowing artesian, but several wells flow and one well has head 90 ft above ground surface
	Triassic (?)		Phu Kadung	2466 m (8088 ft)	Predominantly dark-brown, gray[illegible] brown, grayish-red-purple mic[illegible]us shale and siltstone; and grayish-brown to grayish-red, slabby to massive, micaceous sandstone; basal conglomerate contains fragments from Ratburi limestone	Water-bearing characteristics about the same as those of the Phra Wihan and Phu Phan; quality about the same as the Phu Phan; most wells are nonflowing artesian, but some wells flow
	Triassic		Granite, granodiorite		Mostly porphyritic hornblende biotite, dikes of gabbro or lamprophyre (?) present in places, copper-bearing at Chon Thuk	Wells in decomposed or weathered zones yield considerable amounts of water; the biggest productive well at Sup Muang yields 160 gpm of water at reasonable drawdown; in most places wells yield up to 35 gpm; water quality is generally good

TABLE A9 (continued)

Era	Period	Rock unit	Thickness	Description	Water-bearing characteristics
Paleozoic	Permian	Ratburi limestone	750–2350 + m (2460–7700 ft)	Limestone, gray, dense, crystalline, thin-bedded to massive, with fossiliferous cherty beds and some interbedded shale (slaty shale) and sandstone; locally marble	Drilled wells yield 30 to 500 gpm from cracks, joints, and solution cavities in valley bottoms, low hillsides, and ridges; shale and slaty shale yields up to 69 gpm from joints and cracks; water generally of good quality, total dissolved solids from 290–1100 ppm
	Silurian, Devonian, and Carboniferous	Kanjanaburi series	1000–3000 m (3000–9000 ft)	Shale, sandstone, and sandy shale, gray-green; in places metamorphosed to phyllite, quartzite, and shale; local thin beds of limestone, some marl	Yields 5 to 60 gpm from cracks, joints in shale, sandstone, and sandy shale, in valley bottoms and along streams and slopes; quality is generally poorer than from Ratburi limestone; some is fairly high in sulfate

[a]Based on Haworth et al.,[23] 1966.

over 100 ft thick adjacent to the Mekong, and in places over 320 ft thick along the Nam Mun between Phi Mai and Thathum (Haworth et al,[23] 1966). LaMoreaux[10] (1958, p 27), however, did recognize that terrace deposits occur on some of the flat upland surfaces (between the rivers) throughout the basin areas of the Northeast, an appreciation not so evident in later work limiting any terracing to proximity to present streams, although the presence of gravels on inter-stream ridges is noted (Haworth et al,[23] 1966). Current thinking of soils investigators is that the majority of the soils of the Northeast basin areas are developed on alluvial and colluvial deposits (see soils section). At least three terrace levels exist and there is textural evidence of two substages in two of these.

Geologic studies in Northeast Thailand have primarily been reconnaissances, and very few if any detailed geologic maps have been published. The early work of Lee[25] (1928) set the stage for most of the later work (LaMoreaux et al,[10] 1958; Brown et al,[26] 1951; DMJM,[9] 1961; Haworth,[27] 1962; Haworth et al,[23], 1966) in the Northeast. These works, presenting all geologic maps at small scales, are largely the result of ground-water studies.

A history of the geologic work in the Northeast with a complete bibliography is contained in the forthcoming Department of Mines Ground Water Bulletin 2 (see Haworth et al,[23] 1966). In addition, other maps showing geology are known to have been compiled at a scale of 1:250,000. All these use photography as a basic source of data and none is published. C. R. Warren prepared geologic maps for all northern Thailand at this scale in 1960 as an adjunct to the PACOM Water-Resources studies (1960–1961).[28] His maps and a recompilation at a scale of 1:1,000,000 exist only as rough manuscript copy in the files of the Military Geology Branch, US Geological Survey. C. G. Johnson[29] (1964) prepared a water-resources report and maps at 1:250,000 using and updating the Warren geologic maps through field checking and the results of drilling programs as of about late 1963.

Na Chiangmai and Phiancharon have made some modifications of the geologic map to accompany Ground Water Bulletin 2, based on post-1964 work.[23] Through their courtesy this map is reproduced in its initial draft form as Fig. A7.

Each of these maps progressively supplements all earlier maps, primarily in the definition of the younger Mesozoic sedimentary sequence utilizing results of drilling data and photo interpretation, but to date field data and work can be classed only as reconnaissance, spot observation, and section measuring.

That there is a need for systematic detailed geologic field work in the Northeast has been recognized (Doan, unpublished memorandum recommendations to USOM,[11] 1963; Phiancharoen, personal communication, 1966). However, despite the accelerated program to find water for all the Northeast, sufficient resources have not been available to permit the staff of the Ground Water Division of Thailand's Royal Mineral Resources Department to develop the broad base it needs in budget and personnel. This small but competent group does, however, have a program to map the geology and ground-water resources of the Northeast at a proposed rate of two provinces (or changwads) per year. The changwads of Nakhonrajasima (Khorat) and Khon Kaen are to be completed in 1966. In February 1966 six geologists were working in the Khorat Changwad. Schedules for the following years had not been determined but Udonthani would probably have been next. Field compilation is on a scale of

1:50,000 using the 1952–1953 1:40,000-scale photography. The Mineral Resources Department and the Soil Survey Division of the Department of Natural Resources recognize a basic need for larger-scale topographic base maps and photography on which to compile geology, water-resources, and soils maps.

Soils

The division between soils and unconsolidated geologic rock materials is particularly one of depth, but also to some extent a point of view. In the engineering sense all basically unconsolidated materials are soil, but the soil scientist and agriculturalist consider primarily the upper portion in which diagnostic morphological horizons are developed. Mapping exists of the latter in Northeast Thailand, but knowledge of relations at depth is limited. This is a particular problem in the Northeast in that most of the soils probably have been developed on and from alluvium. Geomorphological studies as such are practically unknown, the existing contributions having arisen from soils investigations (Moormann, Montrakun, and Panichapong,[12] 1964, pp 5–9).

Although precipitation, as one of the climatic factors, plays an important role in soil development, it is the relation of soils to water supply that is of concern here. Soils function directly in the hydrologic cycle and indirectly through supported vegetation as the selective filtering medium between rainfall and the subsurface concentration. Infiltration into the soil affects the ground-water resources; runoff rates affect the surface-water resources. If interception-evaporation effects and transpiration of the vegetation are discounted, the infiltration rate depends primarily on the intensity of rainfall, the entry of water into some soils being inversely proportional to it. The more intense the rain the less the infiltration and the greater the runoff. Infiltration rates are also controlled by the amount and degree of compaction of organic horizons and the physical properties of the mineral soils—their texture, aggregation, initial wetness, and permeability. Minimum infiltration rates, independent of evaporative effects, may vary from practically nil on wet swollen clays to 2 mm/hr on clay loams and 15 mm/hr on deep dry sands. The rates decrease progressively with further wetting as soil aggregates break down and pore spaces become filled.

The soils of the Northeast are characteristic of those developed in a tropical climate of high rainfall and temperature with alternating wet and dry seasons. Soluble bases have been leached causing low pH; hydrolysis and oxidation are intense, and iron and alumina are left in a highly soluble colloidal state. Fertility is commonly very low owing to lack of organic materials, nitrogen, and available phosphorus. The soils frequently have a low cation-exchange capacity. They are commonly granular, which facilitates the entrance of water so that erosion is not serious unless slopes are quite steep. Deposition of iron as lateritic layers has in many places formed a hardpan at varying depths restricting deep water penetration and root development.

Soils mapping in Thailand is at about the same stage as the other environmental sciences although it may be moving forward more rapidly. During the years 1935–1941 Pendleton and associates in the Department of Agriculture and Science made wide-ranging reconnaissance studies culminating in a 21-unit provisional map in 1953 for all Thailand. This map with later minor editions and interpretations still presents the only published map for all the Northeast and is presented as Fig. A8. The soils units used by Pendleton have proved

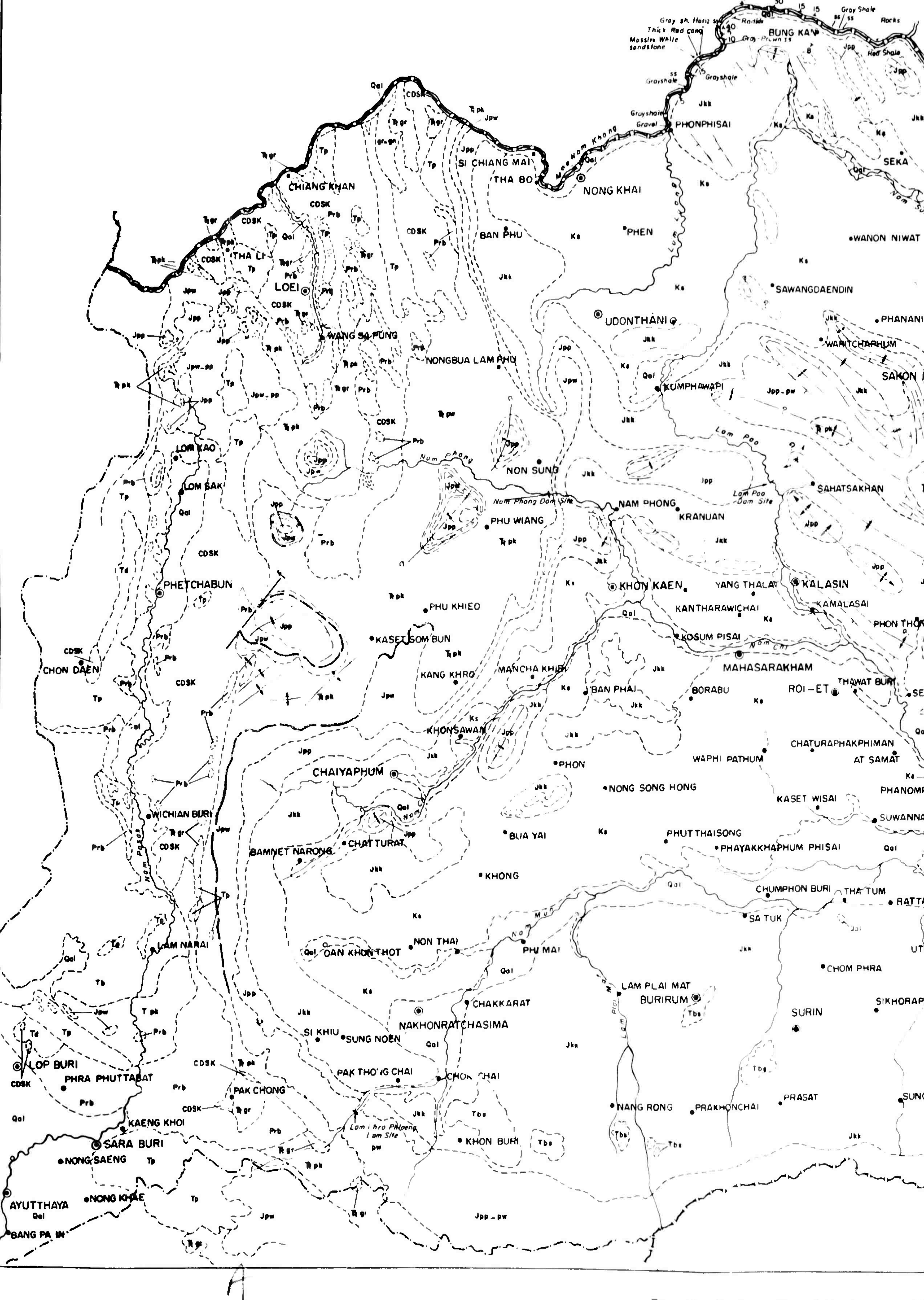
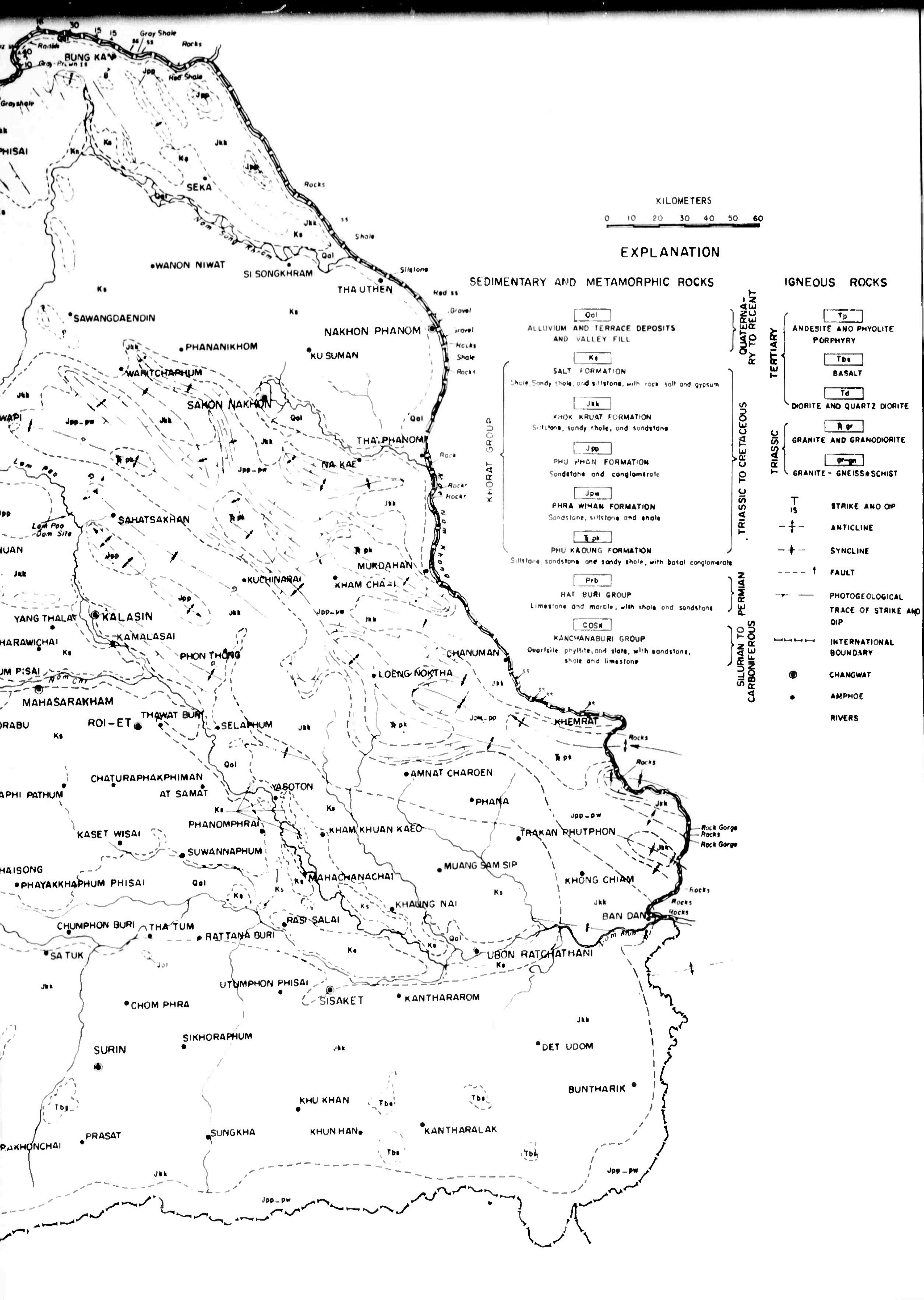


Fig. A7—Geologic Map of Northeastern T

Source: P. No Chiongmoi ond Choroen Phioncharoen, 19



—Geologic Map of Northeastern Thailand

iangmoi and Choroen Phiancharoen, 1965 (unpublished)

B

Chiengmoi, Ta Muong, Rotburi: Recent alluvial soils and some terraces; upland crops, fruit trees, rice, etc

Pimai, Roi Et, Ubon: Low humic gley; low flatlands, from clays to sandy loams; rice, upland crops grown after rice such as legumes, cucurbits, tobacco, etc

Pimai: Clay, low humic gley; rice

Guloronghoi, Roi Et, Ubon, Pimai: Regosols and low humic gleys; flat grassy plains; flood hazard; not suited for crop production unless water is controlled and/or fertilizers applied; rice

Choibodan, Buriram: Clays, dark brown, shallow, concretionary from igneous rocks; upland crops, fruit trees, rice

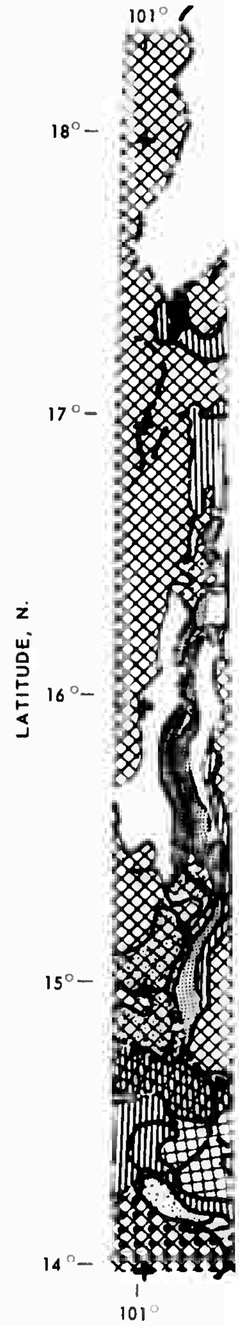
Pokchong, Korat, Probot: Reddish yellow, gray brown, terra rosa; loams and clays from shales, slates, conglomerates, limestones; forest, upland crops; fruit trees

Korat, Nompong, Yasathon: Gray, yellow, red podzolic; upland crops, forest, grassland, fruit trees

Quartzitic and siliceous sandstone hills; gray-brown podzolic; soils usually shallow and in some places stony; forest and upland crops

Rough mountainous land from undifferentiated rocks; gray-brown, red podzolics and lithosols; soils usually shallow, steep, and stony; forest and few upland crops

Place names spelled as in source document.



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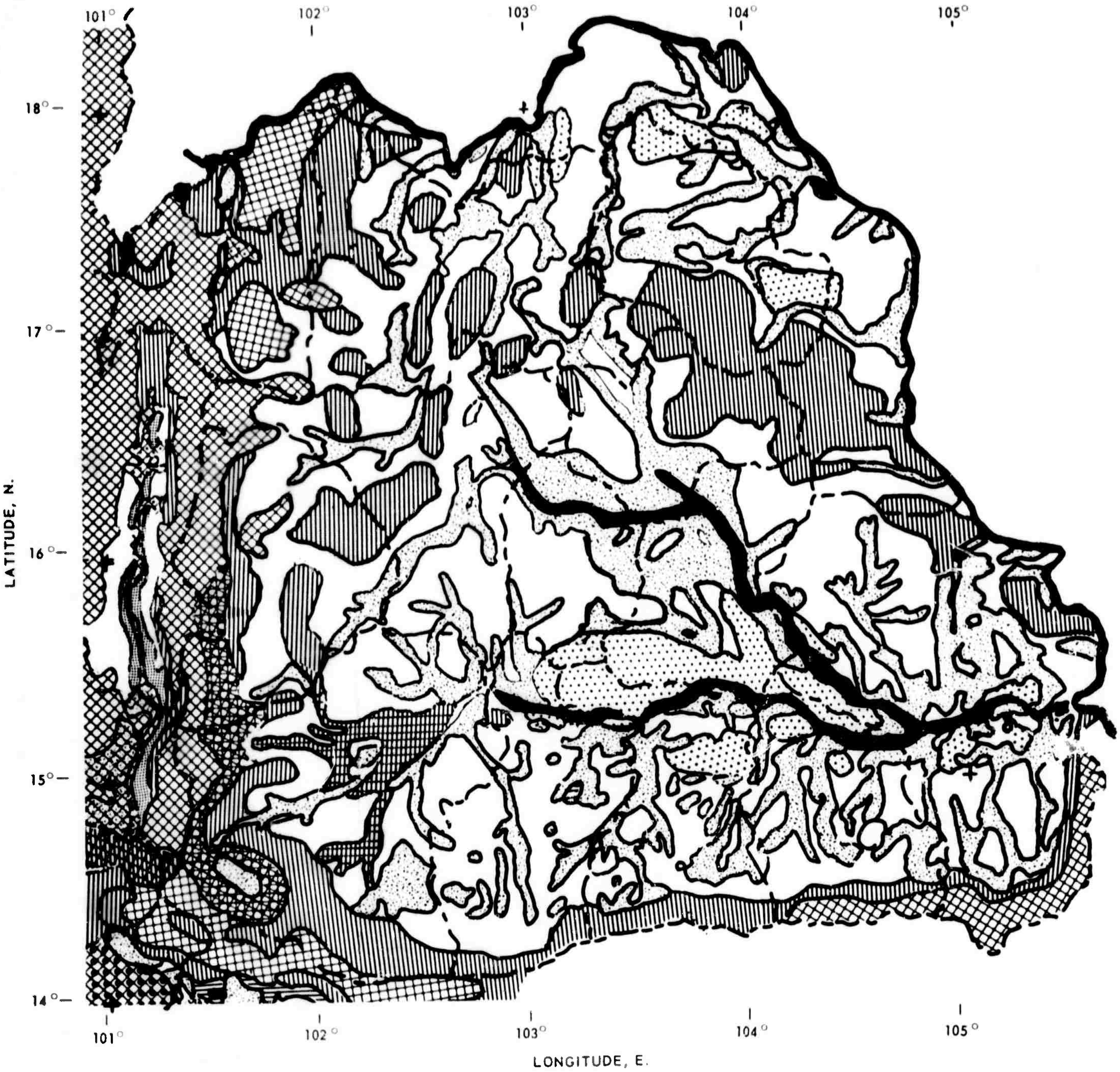


Fig. A8—Soil Associations of Northeast Thailand

From Royal Thai Survey Department, 1964.[13]

B

unsatisfactory for detailed mapping so that the value of this map is limited (Moormann, personal communication, 1966). The field notes collected by Pendleton and analyses of his samples during this period have been recently published (Montrakon, Sarot,[30] 1964) and contain much information.

Later work in the Northeast, largely unpublished, has been done more or less jointly by the Royal Irrigation, Agriculture, and Rice Departments using modifications of Pendleton's units and/or units based on the land-classification schemes of the US Bureau of Reclamation. These works cover small areas primarily related to the irrigation projects. Although these organizations perform some mapping, the responsibility for soils investigations and mapping was assigned to the Department of Land Development, Ministry of National Development, which established its Soil Survey Division in September 1963. This agency, under the FAO guidance of F. R. Moormann and to some degree in cooperation with its predecessors, has produced about 20 published reports in areas of the Northeast.[31] It is carrying on a program to map all the Northeast on a changwad basis to be completed within the next 5 years, the current effort being directed toward the most politically sensitive areas (Fig. A9). By 1968 it will produce a map covering all the Northeast at a scale of 1:1,000,000. Moormann (1966 personal communication) indicated that a complete revision of the Pendleton General Soil Map for all Thailand is scheduled for publication at 1:2,500,000 in 1967.

The Soil Survey Division uses a different basic mapping system (Moormann, Montrakun, and Panichapong,[12] 1964) from that of its predecessors, designed around the system used by the USDA, but believes it can and does translate its units fairly well into land-use and agricultural units. It has no current ability to equate its units to engineering soils units but could do so with proper staffing, guidance, and physical testing equipment. The 1:1,000,000 scale map will use units of the great soil groups (Dudal and Moormann,[32] 1964).

A rough correlation has been made by Moormann between the Pendleton units, the great soil groups, and those of the current system. It is noteworthy that Pendleton's "Khorat fine-sandy loams," reduced in areal extent by the present "Khorat" series but nonetheless covering large areas of the Northeast, are gray podzolic soils. The same soils in South Vietnam are well suited for and contain large numbers of Communist insurgent tunnels.

It is not the purpose of this section to discuss per se the soils units mapped. A list of the current soil series being used in semidetailed and detailed reconnaissance maps is shown in Table A10. Detailed soils maps will use subdivisions or phases of these series, and, for very detailed work, morphometric units may be used. It can be seen that all but the last four units listed have developed on alluvium and are basically related to their topographic levels and to the alluvial materials at these various levels as shown in Fig. A10. Moormann (personal communication, 1966) believes that under proper professional guidance the soils units can be used as a general indication of the occurrence of shallow ground-water resources and also of their chemical quality and perhaps, quantity. The greater the scale and detail of mapping, the greater would be the reliability. Current publications of the Soil Survey Division contain a hydrography section, brief but with data on both the surface-water and ground-water characteristics.

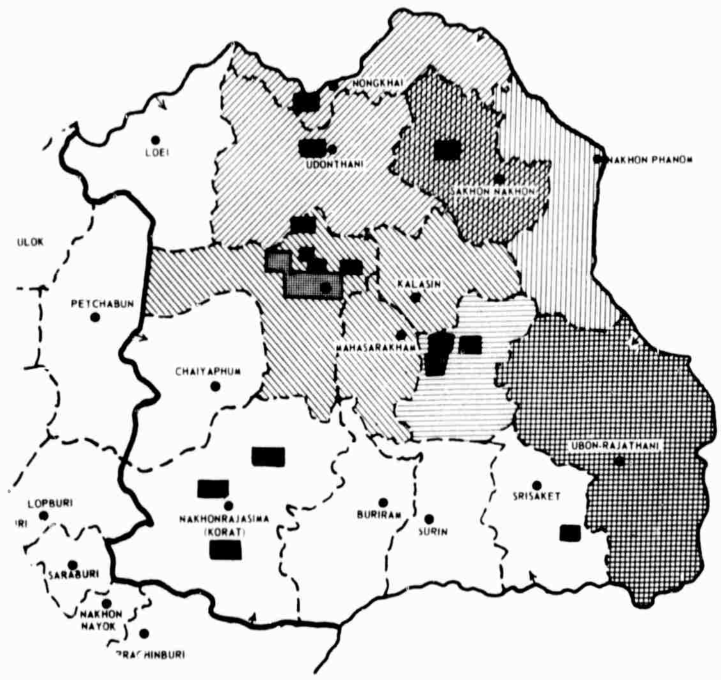


Fig. A9—Recent Soils Mapping Programs in Northeast Thailand

General Soil Map—1:1,000,000 (1:250,000),* 1968

Major projects—1:50,000 (1:10,000–1:20,000)*

- Mobility Environmental Research Study, May 1966; published at 1:250,000 in 1964
- Special request surveys—1:10,000–100,000, 1962–1964

Detailed reconnaissance maps—1:100,000 (1:50,000)*

- Completed June 1966—US Department of Agriculture (USDA) Classification
- Completed Pendleton's Classification; to be revised for USDA Classification
- 80% completed—USDA Classification
- 20% completed—USDA Classification

*Scales in parentheses are those used in compilation.

TABLE A10

Soil Series in Northeast Thailand[a]

Soil series name[b]	Parent material	Physiographic position	Textural profile	Gley	Laterite	Other
Chiangmai (Cm)	Alluvium, recent	River levees, alluvial plain	Variable	No mottling in surface layers	None	—
Rat Buri (Rb)	Alluvium, recent	River levee-basin transition alluvial plain	Mostly clayey	Mottling throughout		
Phimai (Pm)	Alluvium, recent	Basin, alluvial plain	Clayey	Mottling throughout		—
Si Thon (St)	Alluvium and colluvium, recent	Alluvial valleys of creeks	Loamy to sandy	Mottling throughout		—
Kalasin (Kn)	Alluvium, eventually old alluvium	Back swamps of alluvial plain and depressions of terrace	Variable but mostly clayey	Mottling throughout; reduced in subsoil	None	—
Ta Tum (Tt)	Recent alluvium over old alluvium	Flood plain of Mae Nam Mun	Loamy to clayey at less than 50 cm	Mottling throughout	Not at less than 50-cm depth	Subject to flooding
Roi Et (Re)	Alluvium, old	Low parts of low terrace, some on middle terrace	Loamy to clayey at less than 50 cm	Mottling throughout	Not at less than 50-cm depth	—
On (On)	Alluvium, old	Flat, lower parts of low terrace	Loamy to clayey at less than 50 cm	Mottling throughout	Ground-water laterite at less than 50 cm	—
Ubon (Ub)	Alluvium, old	Low terrace (some) and some on middle terrace	Sandy at more than 50 cm	Surface mottling, often mottling in subsoil	Not at less than 50-cm	—
Udon (Ud)	Alluvium, old and recent	Alluvial plain and low terrace	Variable	Mottling throughout	None	Saline
Phen (Pn)	Alluvium, old	Middle terrace, lower formation	Sandy to loamy surface and clayey subsoil	Mottling throughout	Unconsolidated concretions at less than 50-cm depth	—
Sakon (Sk)	Alluvium, some recent, mostly old	All plain, depressions of low and middle terrace	Variable	?	Consolidated ground-water laterite at less than 50-cm depth	—

TABLE A10 (continued)

Soil series name[b]	Porent moteriol	Physiographic position	Texturol profile	Gley	Loterite	Other
Korai (Kt)	Alluvium, old	Low terrace and middle terrace	Loamy sand to sandy; loam usually somewhat heavier in depth	No mottling or mottling only in subsoil	Not at less than 50 cm	—
Nam Phong (Ng)	Alluvium, old	Middle terrace, upper formation	Sand to at least 60-cm depth	No mottling or mottling only in subsoil	Not at less than 50 cm	—
Phon Phi Say (Pp)	Alluvium, old	Middle terrace, lower formation	Variable but usually clayey at less than 60 cm	No mottling in surface, frequently in subsoil	Unconsolidated concretions at less than 50-cm depth	—
Yasothon (Yt)	Alluvium, old	High terrace	Sandy at surface; heavier with depth	mottling	Not at less than 50 cm	—
Berabu (Bb)	Residuum from sandstone or conglomerate	Sandstone outcrops	Sandy surface, often sandy clay, sometimes bedrock at less 125 cm	Often incipient mottling in residuum	Frequent scattered concretions	—
Lop Buri (Lb)	Residuum or alluvium from limestone	Limestone plateaus	Clayey throughout	Indistinct mottling, mostly throughout	None	Gilgai, slickensides
Buriram (Br)	Residuum from basalt	Volcanic cones, basalt outcrops	Clayey throughout	Indistinct	None	Gilgai, slickensides
Pak Chong (Pc)	Residuum from limestone or marl	Limestone plateaus	Clayey throughout	None or weak in subsoil	None	—

[a]From Moormann, Montrakun, and Panichapong,[12] 1964.
[b]The soil series symbol following the series name is used in mapping and in Fig. A10.

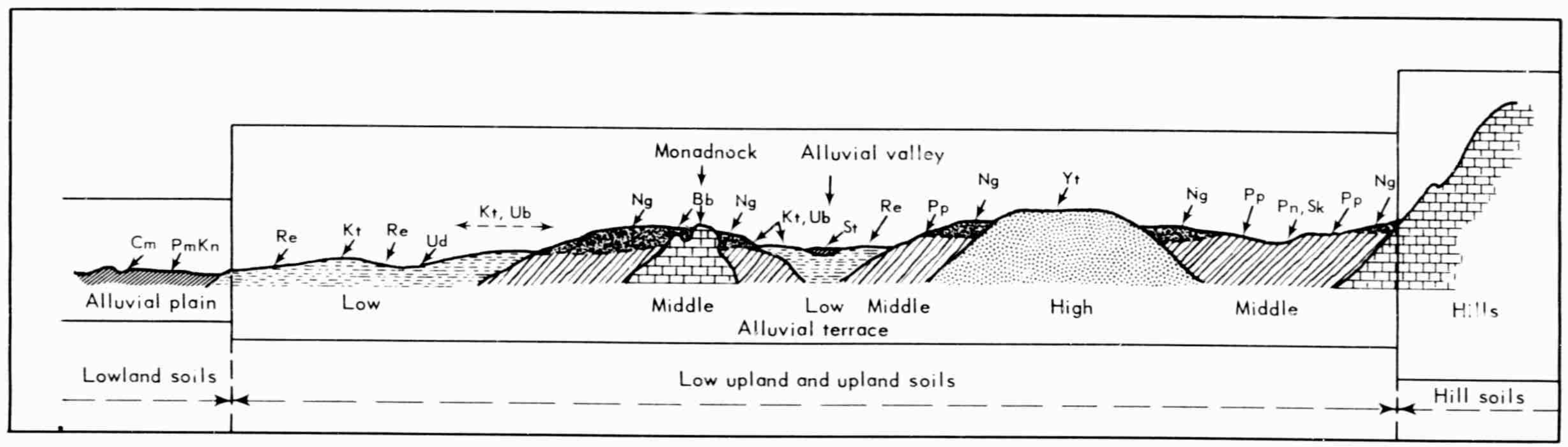
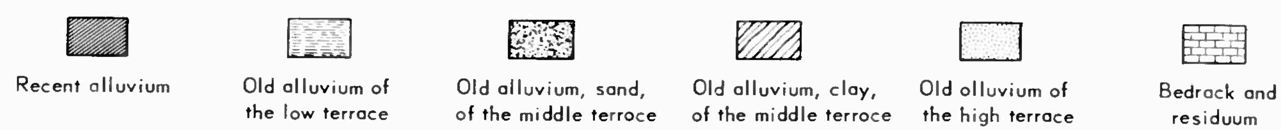


Fig. A10—Schematic Cross Section Indicating the Physiagraphic Position of the Principal Soil Series in Northeast Thailand

Lettered arrows refer to soil series units of Table A10.



Based on Moormann et al, 1964.[12]

The soil mapping now in progress, although admittedly at a level comparable with that of the US in the 1920's, is a major improvement on previous work. In spite of its logistic problems the Soil Survey Division seems to be one of the most active agencies in "getting into the field."

The only other published maps for the Northeast are those of the Upper Nam Chee Basin produced at a scale of 1:250,000 by French soils scientists (SOGREAH,[33] 1960).

Vegetation

Vegetation exerts a positive influence on the water balance of any area. It serves to deplete water resources through growth requirements, transpiration, and the interception of precipitation, which decreases infiltration and increases evaporation. To a lesser extent vegetation can increase water resources by reducing solar radiation at the soil surface and increasing humidity. Through the buildup of a ground humus layer, vegetation increases the moisture-retaining capability of the soil, and, through changes in soil structure, it increases the rate of infiltration and hence decreases runoff.

The value of vegetation in increasing water supplies has not been determined quantitatively or qualitatively for the Northeast and is questionable in many areas, particularly in a tropical monsoonal climate. Whether any of the present plains areas or even most hill areas could serve as a standard for natural or virgin-type vegetation is doubtful. The annual firing of the wood and/or the cutting-burning-planting cycle on the lower slopes probably have been going on since the area was first settled, and the resulting growth, however differing in response to local ecological conditions and human density, produces little shield to solar radiation where it is most needed, and in these places humus layers of any sort are generally absent.

The negative value of vegetation to water resources is far more important in the Northeast and is better known or at least more easily measurable. Transpiration accounts for a substantial part of the losses ascribed to potential evapotranspiration (see section on Hydrology) and may reach 90 percent of the evaporation losses from a comparable area of water surface. Total amount, type, and density of vegetation have some effect on transpiration losses (i.e., broad-leaved, evergreen, and deep-rooted plants present more surface, longer period, and greater depths from which to effect transpiration). Dewiest[34] (1965), however, indicates that an increase in size of crop or plant does not lead to any significant change in the amount of water used, although grass transpires less than forest.

Transpiration is, like evaporation, essentially a surface phenomenon. Its effects, except perhaps for phreatophytes, rarely go below 0.7 m for any but the largest and deepest-rooted plants, and evaporation (ignoring capillarity) is limited to roughly the top 10 cm of soil. Waters that infiltrate below these depths supposedly recharge the ground-water resources. How much precipitation infiltrates is partly a function of how much is intercepted by plants; how deeply it infiltrates is controlled by the number and depth of the absorbing roots. The physical effect of a forest in reducing infiltration by interception is very great. Removing the forest, particularly by burning, may decrease interception and transpiration, but it increases evaporation from insolation. The long-term

effect on the total environment thus negates cutting or burning as a plausible method of water saving in the Northeast. Kambhu[35] (1961 revision) states, "The occurrence of flash floods after heavy rains and acute dryness in the dry season is on the increase as deforestation is being continued."

The vegetation distribution in the Northeast is known only generally; existing small-scale maps vary widely in purpose and in both unit descriptions and boundaries. Continued rapid population growth, the impetus of irrigation projects, and the short-term use of upper slopes makes any mapping, particularly of detailed units, a tenuous operation at best. Roughly 70 percent of the Northeast can be grouped into a forest, grassland, and wasteland category. The remainder, collectively, is farmland, of which 75 percent is cropland, the other 25 percent being a mixture of farmsteads, idle or fallow lands, pasture, and small woodlands. These percentages are generalized; stated proportions of any type or subtype vary with source and data. Plants have been used as indicators of shallow subsurface waters in many places of the world. Such plants, known as "phreatophytes," have not been so identified in the Northeast but may offer possibilities for local use.

Roughly 70 percent of the forested land in the Northeast is classified as dry dipterocarp forest (Knud Christensen, personal communication, 1966) or, alternatively, dry monsoon forest (Rojanasoonthon,[30] 1964). These trees are more or less deciduous and commonly grow to 25 and, rarely, 30 m tall. Canopies range from closed to very open, but foliage is commonly so sparse that solar radiation can reach the ground layers. Commonly a shrub layer occurs that may not be present everywhere because of fires and may be replaced locally by low bamboos. The herb layer is commonly dense and in places largely grassy in heavily burned areas. Thorny and climbing plants are common. The present flora is adapted to xerophytic conditions and contains a large number of fire-resistant plants (pyrophytes). The long-term effect of man and/or naturally occurring annual fires may be the principal factor in the establishment of this forest type and all its many modifications to thorny scrub and savanna. At present sapling reproduction is very limited in most places. Dipterocarp-forest growth on the extensive low and medium terraces is generally poor and sparse. Better growth and more varieties of trees are associated with the better-drained deeper soils of the high terraces and hills. The high borders surrounding the plains areas, including much of the Phu Phan Range and scattered higher hills within the plains, are occupied by mixed deciduous and/or evergreen forests with dense closed canopies in places. Old openings in the wetter parts of such forests, whether natural or man made (rai cultivation), are commonly filled by dense growth of tall bamboo.

Work currently being done by the Environmental Branch of Military Research and Development Center (MRDC) on classification of forests provides a substantial data base from which to make a better forest map of the Northeast.

Farmlands form an appreciable part of the vegetated land of the Northeast and by far the major part in the populated areas. Farming needs are part of the total water problem since agriculture consumes the largest amount of water.

Roughly 70 percent of the cultivated cropland is in padi. The remainder produces a variety of crops but principally truck crops, maize, kenaf, sugarcane, cotton, peanuts, castor beans, pineapple, bananas, tobacco, and tree

fruits. Approximately 20 percent of the cropland was irrigated in 1964; the rest depended on rainfall or river flooding.

From May to September, rainfall is adequate for vegetal needs but is deficient (see the section "Climate") for the remainder of the year, being least adequate between February and April when soil moisture is exhausted and plant life is critically dependent on rainfall and/or irrigation. Molagool[16] (1962) determined on the basis of supply and demand that rainfall is sufficient to irrigate no more than 10 to 15 percent of the Northeast for year-round crop production. He stated (1962) that because about 10 percent of the region would be under cultivation in any one year it would therefore not be possible to extend the area of cultivation unless additional water were brought in from the Mekong.

Moisture requirements of crops differ with plant types, surface and subsoil types, and climates, particularly with respect to the amount and distribution of precipitation. The requirements have been roughly calculated (Israelson,[36] 1965) for some of Thailand's crops to determine irrigation requirements (Table A11); of the principal crops grown in the Northeast, rice exerts the greatest demand.

TABLE A11

Water Requirements Including Rainfall for Different Crops in Thailand[a]

Crop	Duration of water requirement, months	Water required, including rainfall, depth over the area, cm
Rice	3.5–6	108.2–151.1
Sugar	9.5–12	180.0
Jute, Bengal	3	69.2
Cotton, August sown	5.5–6	90.0
Cotton, December sown	5.5–6	62.5
Peanut	3–4	50.4
Soybean	3	40.9
Maize	2.5–3	39.7
Potato	2.5	26.0
Sweet potato	2.5–3.5	39.0
Green manures	2–7	35.0–62.0

[a]From Samchook Experimental Station, Rept 1.[36]

The variation and undependability of the rainfall is as much a problem to the farmers as its seasonal lack. The area planted to rice, or harvested, varies with the annual water budget and pattern. In wet years unpaddied upland rice may be attempted in the higher ground. In many years there is a shortage of water in June at the beginning of the rice-growing period and another near the end in September, either of which damages crops. Long[37] (1963) indicated that floods and droughts cause appreciable crop reductions in planted lands. Drought was the chief cause in Khon Kaen Changwad, accounting for 57 percent of the damaged padi lands between 1957 and 1961. Droughts also control the amount planted; in the crop year studied the farmers had planted on the average only

68 percent of their agricultural land and harvested only 88 percent of what was planted.

In theory, padi lands should be a net benefit to ground-water resources because the diked (0.3 to 0.4 m high) fields (15 by 30 m) temporarily retain a large amount of the rainy season's waters; the impetus toward more irrigation (see the subsection "Surface Water") could extend their use seasonally and afford new areas for padi or other crops. Imperfectly drained soils, however, are desirable for padi, although enough surface and subsurface drainage must be available to provide long-term salt balance and sufficient aeration. Existing fields through generations of use have fostered a relatively impermeable pan in the padis and the underlying soils are commonly dry until late in the season. Water does not infiltrate to any depth but remains as a very shallow water body. Most of the soils proposed for irrigation are also inherently low in permeability and transmissibility because of fine-textured material throughout the profile or because of strong soil-profile developments with impervious laterites at shallow depths; hence the net expected one-season effect may add little to ground waters. With long-term or all-season irrigation the high water tables may be sustained or even augmented by the continued steady replenishment, however slow. Some possible detrimental factors involved in such irrigations are discussed in the section "Surface Water" of App B.

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Appendix B

HYDROLOGY AND WATER RESOURCES OF NORTHEAST THAILAND

Figures

Tables

HYDROLOGY

The central concept of the science of hydrology is the so-called hydrologic cycle—the circulation of water from the oceans through the atmosphere to the land and thence by runoff overland or by infiltration and underground movement back to the sea or, alternatively, back to the atmosphere by evapotranspiration. Figure B1 diagrams the natural hydrologic cycle together with modifications made in it by man. For Northeast Thailand, evapotranspiration has been found to account for 1022 mm or 80 percent of the total precipitation (1277 mm).[16] Infiltration (96 mm) accounted for 7.5 percent and runoff, 159 mm or 12.5 percent. As evapotranspiration is thus a major factor in the water balance of the Northeast it will be outlined below. Other factors in the hydrologic cycle are discussed elsewhere in this appendix and in App A.

A large amount of the water precipitated on the earth is returned to the atmosphere as vapor through the combined actions of evaporation and transpiration, collectively termed evapotranspiration. Evaporation, or vaporization, is the process by which molecules of water at the water surface or in moist soil acquire enough energy through solar radiation to escape the liquid and pass into the gaseous state. Evaporation takes place so long as the atmosphere is not saturated and moisture remains to evaporate. The rate of evaporation depends primarily on temperature, relative humidity, wind velocity, and to a lesser extent barometric pressure and dissolved solids in the water. As temperature falls, relative humidity increases and the rate of evaporation decreases. Wind promotes evaporation because it sweeps away vaporized water molecules from the surface of evaporation. The effect of everyday variations in barometric pressure on evaporation is minor. Dissolved solids reduce evaporation approximately in proportion to the concentration of solids in solution.

Water vapor is also "breathed" into the air by animals and plants. Most of the water absorbed by plants is passed into the atmosphere; some plantations release almost as much water into the air as would rise from a comparable area of water surface. Transpiration, the process by which water from plants is discharged into the atmosphere as vapor, depends essentially on the same factors as those that control evaporation, viz, air temperature, wind velocity, and solar radiation. Transpiration also varies with the species and the density of plants and to some extent with the moisture content of the soil, in that a certain amount of water must be available to plant roots (the wilting coefficient) without which the plants will die.

Evapotranspiration is considered a regional loss of water although in the strict sense the word "loss" applies only to evaporation, since plants use the water in much the same way as humans and industries but without polluting their wastes.

Evapotranspiration is very difficult to measure, particularly where the supply of water is limited. The only standard measures of evaporation are

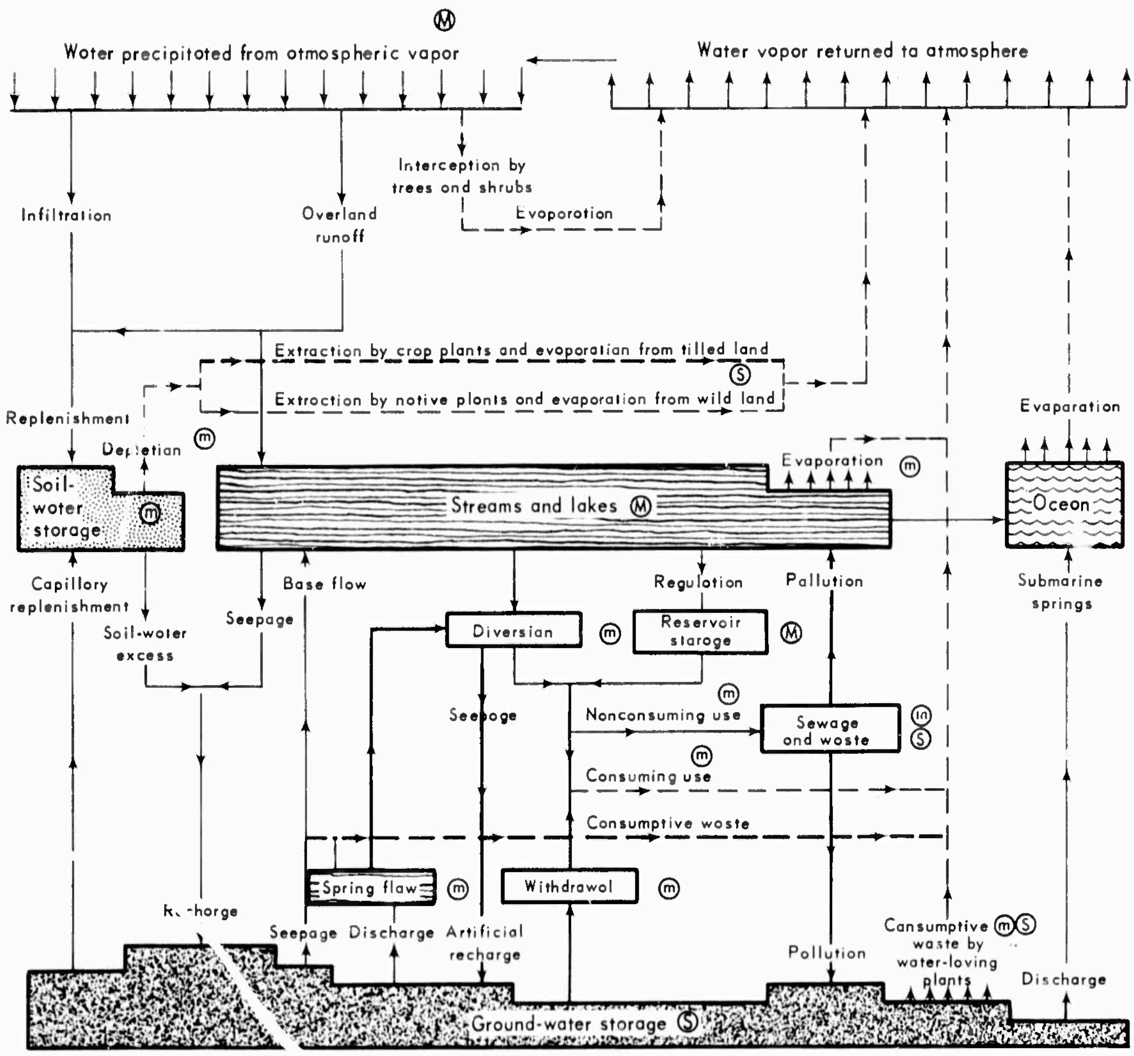


Fig. B1—Hydrologic Cycle

Solid flow lines indicate mov ment of water as liquid; broken lines, movement as vopor. Heovy flow lines (lower central part o diogram) indicate mon's principal chonges in the naturol cycle.

M, components of the cycle for which records of meosurements ore common ond foirly extensive, though not everywhere comp hensive; m, components thot ore not measured readily, ond for which more extensiv records ond improved techniques of meosurement are needed; S, compon ts of notural woter consumption thot con be, or ultimotely must be, salvaged in substantial port.

TABLE B1

Potential Evapotranspiration in Northeast Thailand[a]

(In millimeters)

Station[b]	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Phetchabun	76	117	155	169	176	161	161	152	147	139	104	72	1628
Loei	52	125	116	150	172	164	162	154	141	120	81	56	1492
Udon Thani (Udon)	68	97	151	167	177	171	171	162	149	138	105	68	1624
Nakhon Phanom	61	82	144	162	171	164	162	155	142	128	88	61	1522
Sakon Nakhon	63	84	148	164	173	168	166	160	145	130	86	63	1548
Khon Kaen	76	109	159	169	178	168	161	161	148	139	99	72	1645
Roi Et	82	109	159	169	178	161	169	161	142	136	104	72	1647
Chaiyaphum	87	109	159	171	183	167	156	155	142	132	105	82	1647
Ubon Rachathani (Ubon)	87	118	157	167	174	164	165	158	145	136	105	82	1657
Surin	87	124	162	170	178	168	164	161	149	139	105	82	1687
Nakhon Rachasima (Khorat)	83	125	160	168	175	165	168	161	147	136	105	74	1667
Mukdahan	62	91	153	167	176	165	166	158	147	131	91	64	1572

[a]From SEATO Graduate School of Engineering, Bangkok. Thesis No. 73. "Pamong Project: Water Utilization for Irrigation, Navigation and Power," in US Bureau of Reclamation reconnaissance report.[15]

[b]Place names spelled as in source document.

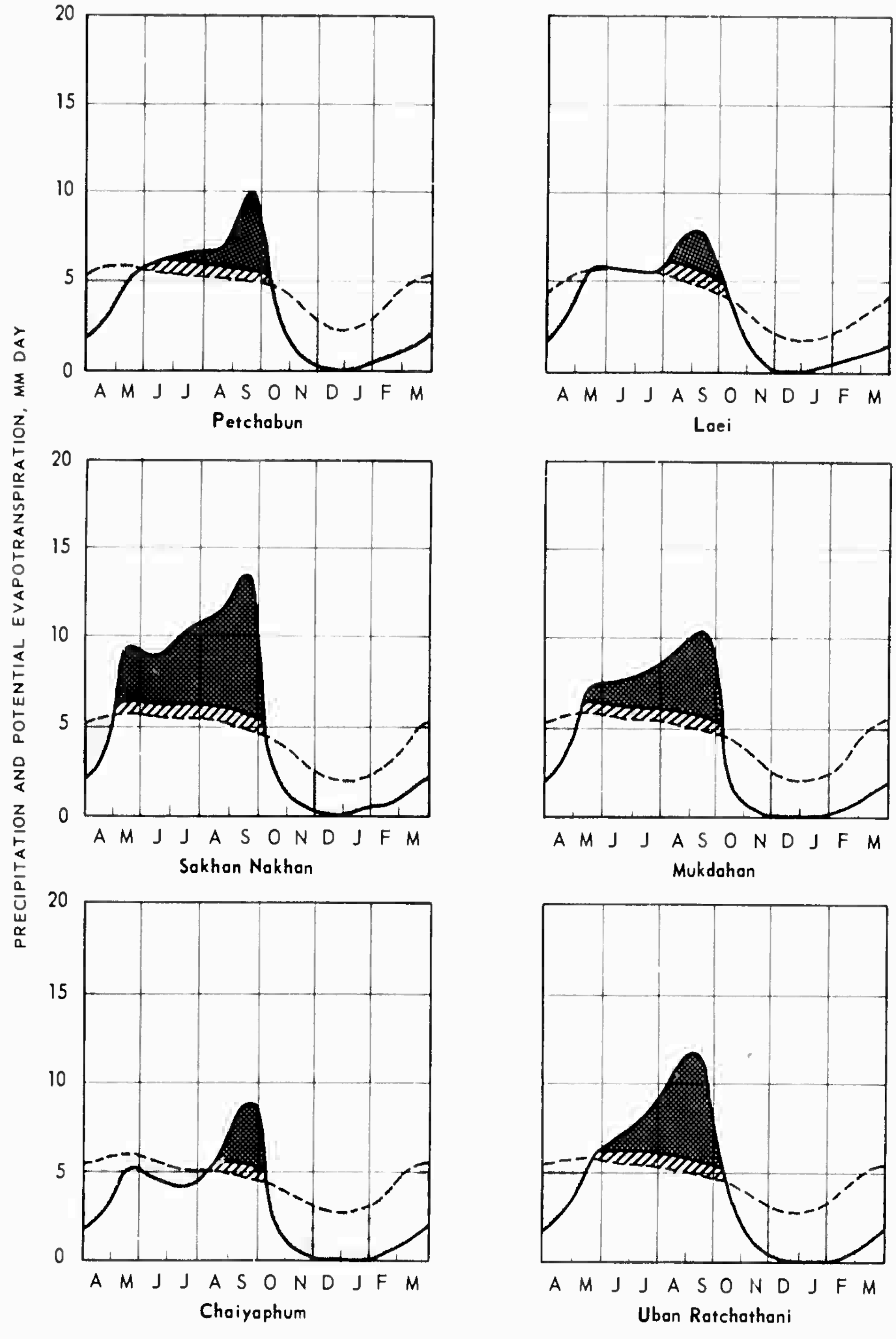


Fig. B2—Seasonal Variation of Precipitation and Potential Evapotranspiration for Various Stations

Infiltration curves based on observed runoff in the Mune and Chee rivers, 1951–1960. From Malagool,[16] 1962. Place names spelled as in source document.

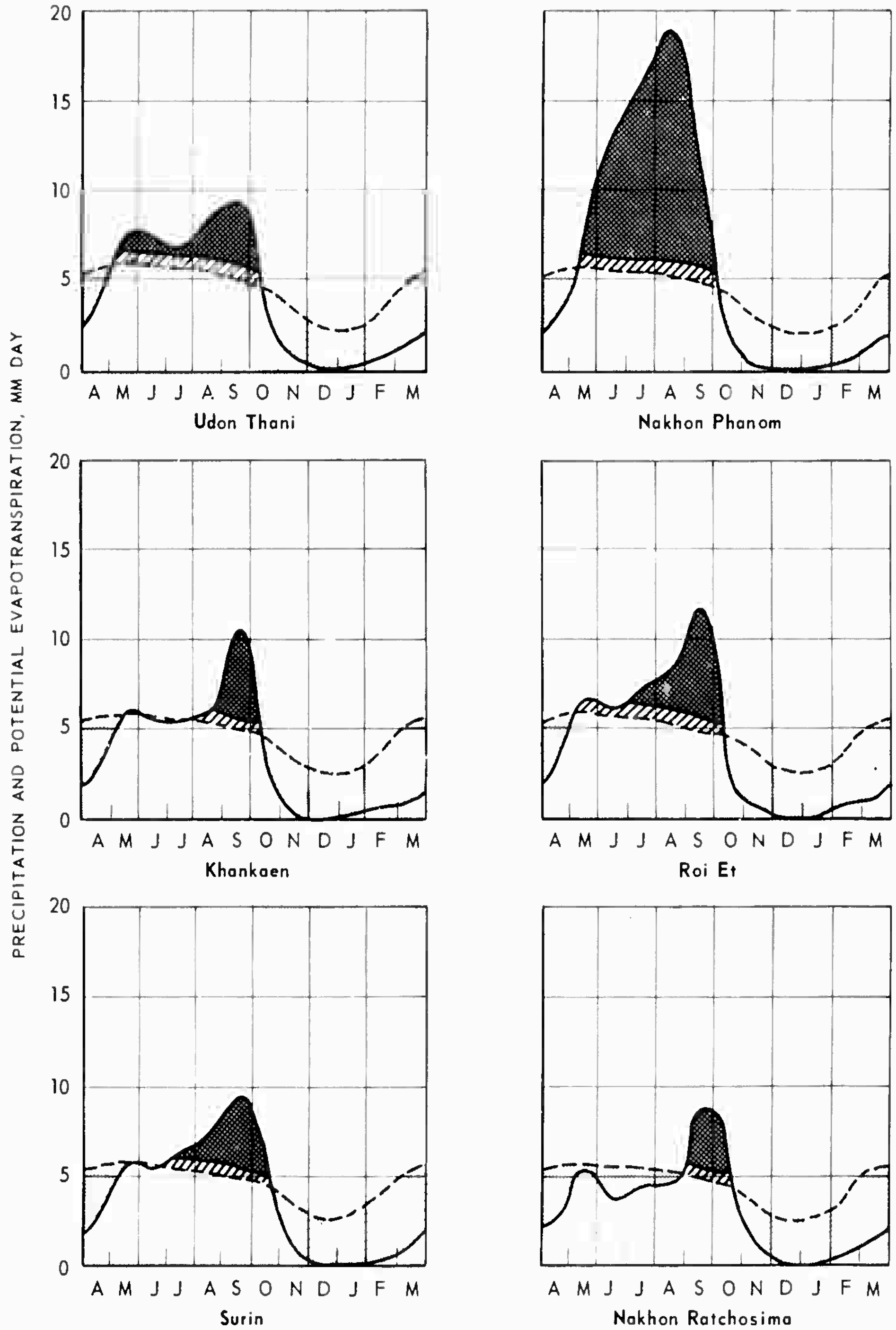


Fig. B2—Continued

——— Precipitation curves based on Meteorological Office statistics for 1931–1960

- - - - Potential evapotranspiration curves calculated by Thornthwaite's method using temperature statistics for 1937–1960

Runoff   Infiltration   Soil Moisture Deficit

those from a large vegetation-covered land surface with adequate moisture at all times. This condition defines potential evapotranspiration, or water need, and is the standard unit of measure. Because in this case moisture is not restricted, potential evapotranspiration is limited solely to the available energy that heats the ground and air and supplies the latent heat for evaporation of water. Where there is a shortage of water, actual evapotranspiration will be less than potential evapotranspiration. Although the overall rate of actual evapotranspiration depends on the climate, soil-moisture supply, plant cover, and land-management practices, the first two are by far the most important. Because, by definition, potential evapotranspiration is not limited by deficient soil-moisture supply, it is affected almost entirely by climatic factors.

In the Northeast potential evapotranspiration (Table B1[15]) follows a more regular cycle than precipitation (Table B2) because temperature, humidity, and air movement are relatively steady. Potential evapotranspiration is highest in May, varying from 171 to 183 mm/month, depending on location. It is least in December, the cooler weather bringing the rate down to 56 to 82 mm/month.

TABLE B2

Soil-Moisture Deficit[a]

(In millimeters)

Station[b]	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Annual
Petchabun	44.1	84.5	71.8	66.4	90.9	108.2	91.2	16.1	—	—	—	573.2
Loei	9.7	60.7	53.8	41.3	106.0	80.6	59.0	—	—	—	—	411.1
Udon Thani	19.2	87.9	63.4	60.3	77.8	111.2	70.6	—	—	—	—	520.4
Nakhon Phanom	63.7	81.7	58.3	56.5	68.3	122.0	81.0	—	—	—	—	531.5
Sakon Nakhon	60.0	72.9	62.2	56.0	63.8	93.5	80.3	—	—	—	—	488.7
Mukdahan	80.9	85.6	61.8	58.9	80.0	108.4	83.7	—	—	—	—	559.0
Khon Kaen	48.0	90.2	69.2	69.7	89.8	130.3	95.7	—	—	—	—	592.6
Roi Et	62.7	90.6	69.0	79.5	84.7	123.5	78.2	—	—	—	—	588.2
Chaiyaphum	46.6	90.8	80.6	84.9	94.9	114.3	97.8	34.8	30.2	34.4	—	709.3
Ubon Ratchathani	4.5	78.3	79.6	81.4	108.0	117.1	95.5	2.0	—	—	—	566.1
Surin	—	75.3	80.9	85.1	111.8	118.3	98.5	6.6	—	—	—	576.5
Nakhon Ratchasima	—	67.9	70.8	76.1	92.0	114.9	85.1	18.1	54.2	36.2	21.7	637.0

[a]From Molagool,[16] 1962.
[b]Place names spelled as in source document.

Potential evapotranspiration is less than precipitation during the latter part, if not the whole, of the wet season (Fig. B2). During this time rainfall exceeds the combined evaporation and infiltrative capacities of the soil, vegetation, and atmosphere, and some of the water runs off. Potential evapotranspiration is less than or only slightly in excess of precipitation in the early part of the southwest monsoon in the central and western parts of Northeast Thailand, and saturation is not reached until September. Along the eastern margin of the region, precipitation is well in excess of potential evaporation throughout the wet season. During the remainder of the year, the dry season, potential evapotranspiration exceeds rainfall by a wide margin. Infiltration that does occur during occasional storms in this period does not get past the root zone. Evapotranspiration requirements exceed rainfall and the soil moisture is depleted,

the worst period being between February and April (Table B2). Plant life is then dependent entirely on rainfall or irrigation.

Surface-water resources become abundant during the wet season together with a gradual buildup of the subsurface water resources. Surface water persists, but as a rapidly diminishing resource, into the early part of the dry season. Subsurface, or ground-water, resources reach a peak in the post-rainy-season transition period and begin to diminish throughout the dry season but are only gradually recharged in the wet season. The shallower and commonly perched ground waters drop most rapidly, but deep sources also diminish somewhat in many places.

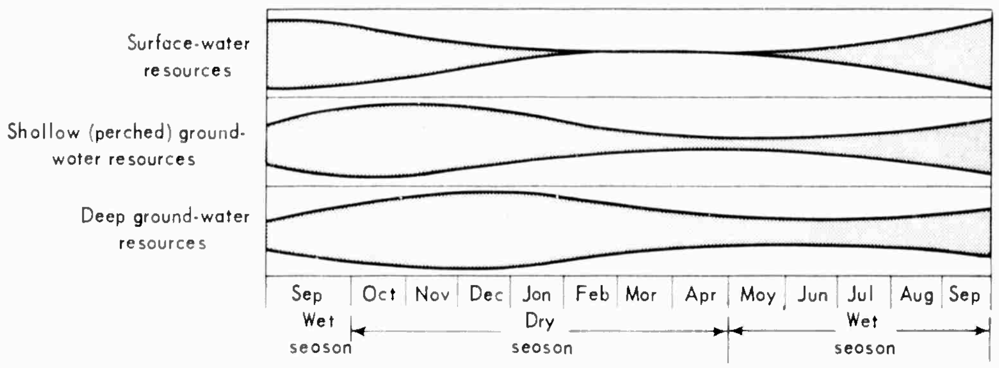


Fig. B3—Seasonal Relations of Water Resources in Northeast Thailand

These relations are expressed diagrammatically in Fig. B3. In terms of water-supply problems it can be seen that, during the critical dry season, deep ground-water resources would be the most reliable, followed by shallow ground waters, and finally the natural surface-water supplies. Artificial augmentation by surface-water impoundments or subsurface recharge can locally increase the total resources. The following sections discuss some of the theory and work being done in understanding and developing these resources.

SURFACE-WATER RESOURCES

General

During the wet season surface-water resources are available everywhere from streams, natural depressions, buffalo wallows, flood waters, and the thousands of holes, ponds, and diked drainages created over hundreds of years by the farming population. Man has seemingly taken every possible advantage of the low gradients available around his villages and cultivated ground to catch and preserve the waters of the rainy season for domestic and animal use and for padi culture, although such efforts are generally of small scale and essentially fairly primitive. LaMoreaux, however, (personal communication, 1967) notes that ". . . in many arid countries such as Libya and the North Egyptian coast, tunnels and large underground storage rooms have been constructed in which

substantial volumes of water have been stored that are not subject to high evaporation losses. In certain areas [of Northeast Thailand] underlain by relatively impermeable beds, such storage facilities could be developed with relative ease." Presumably little addition can be made within the capabilities of the individual or small groups of farmers. Road construction, particularly of the raised all-season types, has added substantially to these sources by the ponding of borrow pits and the local damming effects of roadbeds. More deliberate efforts of the government have added and will continue to add to surface-water resources through construction of ponds, tanks, and reservoirs. The total of all human effort plus the natural poor drainage of the plains results in visible surface-water resources that are impressive in area. These were very evident in aerial observations made over most of the Northeast in mid-January 1966 after a dry year.

That man's early efforts were not enough, at least to keep pace with more recent spurts in population growth, is suggested by current voiced needs for water, which are threefold: (1) domestic purposes, (2) stock watering and care (no small requirement when the dominant beast of burden and meat supplier is the water buffalo), and (3) the growing of subsistence and commercial field crops. Lack of water for any one need would, and locally does, produce human failures and minor disasters in the Northeast. Although this paper is concerned with the first need, addressed to counterinsurgency-related problems, all three must be considered because they affect each other in various contexts.

Surface waters are everywhere the most easily located and the most accessible water resources. They are also the most sensitive to local or seasonal drought. As this sensitivity is the essence of the surface-water-resources problem in the Northeast, only the dry-season resources are considered here. The few rains that do fall in that season contribute little if anything to the natural water supplies. Light-storm rainfall may be almost entirely depleted through interception by vegetation and subsequent rapid evaporation. Rain that reaches the ground temporarily fills puddles and surface depressions or infiltrates immediately and is absorbed by the soils.

Data Limitations

That the natural and artificial surface-water resources will decrease substantially or disappear during the dry season is more or less a foregone conclusion from the lack of precipitation, high evaporation rate, and lowering ground-water tables. Just how much, where, and when, however, are not known in detail. Particularly lacking are data that would be of value as guides to limited-scale military operation, i.e., map data.

Most published hydrologic statements deal in gross generalities: "Most of the water courses and the rivers flow only in July and October" (Kambhu,[35] 1961); "All rivers . . . have intermittent flow and the upper reaches are frequently dry. . . ." (Haworth,[22] 1966) ; "Only the Chi and Lam Mun flow in the dry season and then only in the lower reaches."[15] Soils studies, generally in support of specific irrigation projects, come closer. In a study of the Khon Kaen area, Rojanasoonthon[39] (1964) states that the main rivers—the Nam Phong, Lam Choen, and Lam Chi—and the lower courses of their tributaries contain water the year round. The few water studies prepared for military guidance (Johnson,[29] 1963; PACOM,[28] 1961) treat surface waters in general terms or

apply data and interpretations apparently obtained primarily from the Army Map Service (AMS) topographic base maps. There is no reason to believe that the stream data shown on these maps, prepared largely from photographic interpretations, are sufficiently reliable.

The RTG Department of Mineral Resources has a Ground Water Division but no Surface Water Division comparable to the one in its counterpart, the US Geological Survey. Surface waters are principally investigated by the Royal Irrigation Department although it seems not to make water analyses (see the section "Quality"), to keep data on perennial stream locations, or even to staff all streamflow stations. Streamflow stations normally provide the basic data for evaluating surface-water flow, but, as shown below, there are too few stations, and those existing were located primarily to obtain information for specific potential irrigation projects.

Stream-Measurement Data. Streamflow is usually considered synonymous with runoff, a measurement expressed either as cubic feet per second (cfs) or, in the metric system, cubic meters per second (m^3/sec). "Runoff" as a part of the hydrologic cycle concerns the eventual discharge of water from a basin or area through the channels of surface-drainage systems. The term "runoff cycle" is used to describe the distribution of water and the paths it follows after precipitation on land until it reaches stream channels or else returns directly to the atmosphere through evapotranspiration. Runoff is thus the sum of surface runoff plus ground-water flow that reaches the streams. Surface runoff equals precipitation minus surface retention (which is the sum of interception, evaporation, and depression storage) plus infiltration.

The total runoff of the Northeast has been given as about 28 billion m^3/year, of which 75 percent is from the Lam Mun Basin. Of this, roughly 95 percent occurs in the period May–October. The Bureau of Reclamation[15] estimates that for the entire Lam Mun drainage basin the mean annual runoff varies from 12 to 28 percent of the total precipitation.

Streamflow records, like most other statistical data in the Northeast, are of short duration (Fig. B4) and perhaps of nonuniform measurement. Both the Royal Irrigation Department and the National Energy Authority collect streamflow data. Comparative records at one site (Nam Phong) for 1962 show monthly differences up to 28 and an annual difference of 72 million m^3. Monthly and annual runoff data from five selected stations are shown in Tables B3 and B4 together with the deficit and runoff coefficients as determined by Molagool[16] (1962), who concluded that the specific yield of about 5 liters/sec/sq km was probably a constant over the Lam Mun and Lam Chi. However, on indirect evidence from the water balance, yields and runoff coefficients might be higher in the northern basin.

These station records do accent the wide differences in flow. At the height of the flood season, in October, the mean monthly flow of the Lam Mun is 2001 cm/sec at Ubon Ratchathani, whereas 5 months later it is only 12 cm/sec. The range in variation of monthly flows is from 370 percent down to 2 percent of the long-term mean flow; the range of extremes of highest flood and smallest dry-season flow is even greater.

Stream-measurement data from 22 stations, including 3 on the Mekong for comparison, are shown in Table B5. Maximum and minimum flows (discharge) are shown by date of month, although actual highest-water periods

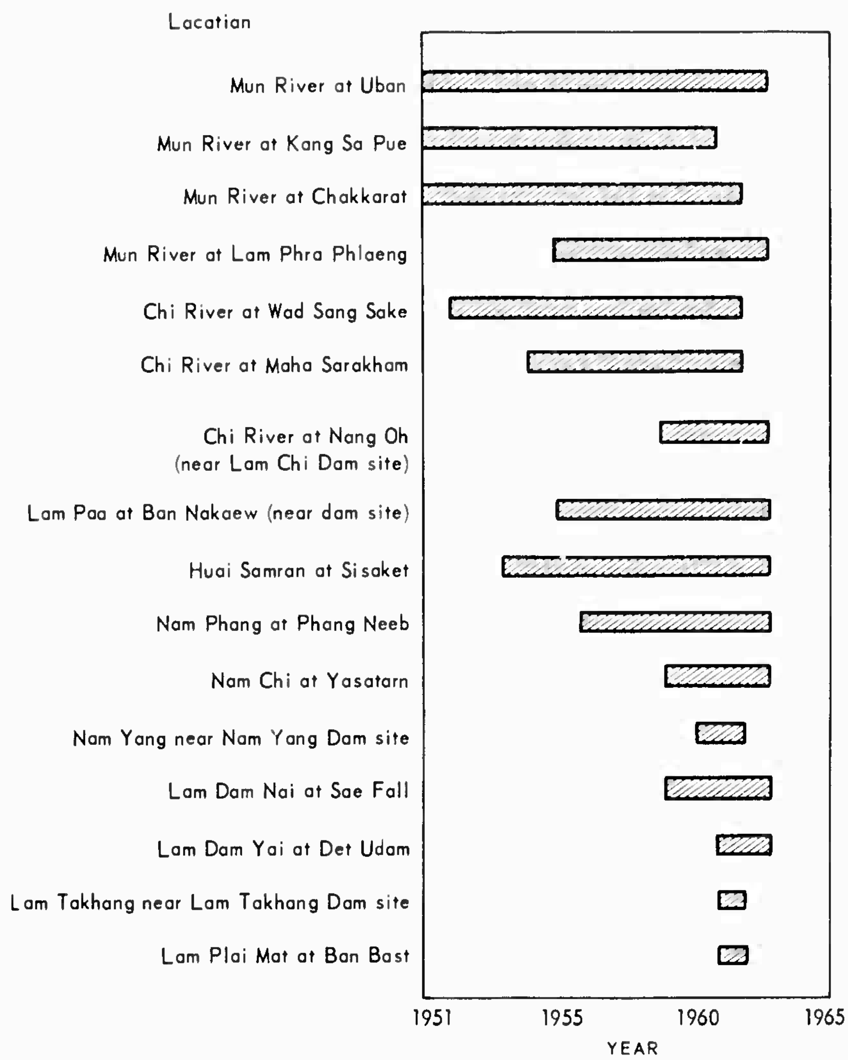


Fig. B4—Period Covered by Streamflow Records—Mun and Chi River Basins

From US Bureau of Reclamation,[15] March 1965.
Place names spelled as in source document.

TABLE B3

Runoff Data from Specific Stations in Northeast Thailand[a]

Station[b]	Drainage basin, sq km	Mean annual rainfall, mm	Runoff, mm	Deficit, mm	Runoff coef[c]	Mean annual runoff: In m³/sec	Mean annual runoff: In m³ × 10⁶	Mean annual runoff: In liters/sec/sq km
Lam Mun at Ubon	105,110	1277	162.2	1115	0.127	540.4	17,042	5.1
Lam Chi at Yasothon	44,630	1234	158.2	1076	0.128	228.8	7,057	5.0
Lam Chi at Mahasarakham	28,420	1173	158	1015[d]	0.135[d]	117.1	3,693	4.1
Lam Chi near Khon Kaen	10,390	1115	155.3	960	0.139	512	1,615	4.9
Pong at dam site	11,730	1221	165.0	1056	0.135	61.4	1,936	5.2

[a]Based on Molagool,[16] 1962.
[b]Place names spelled as in source document.
[c]Calculated with an allowance of 20 mm/month for infiltration.
[d]Estimated from specific yield.

TABLE B4

Mean Monthly and Mean Annual Runoff[a]

(In cubic meters per second)

Month	Location[b] and period covered: A 1951–1960	B 1951–1960	C 1955–1956	D 1954–1959	E 1957–1960
Apr	13.1	10.3	4.0	4.8	2.3
May	10.2	26.1	16.5	13.8	18.5
Jun	170.5	146.3	235.5	36.8	22.5
Jul	378.1	218.7	269.0	50.6	35.3
Aug	784.8	312.5	182.5	43.6	55.2
Sep	1477.4	722.3	360.5	148.4	265.6
Oct	2001.0	738.3	250.5	230.8	306.8
Nov	1268.6	406.3	24.5	59.5	23.1
Dec	292.5	73.1	11.5	11.7	4.3
Jan	34.6	13.0	9.0	6.0	1.6
Feb	15.0	10.1	8.0	5.0	1.1
Mar	11.8	8.5	4.0	4.0	0.5

[a]From Molagool,[16] 1962.
[b]

Symbol	Location	Drainage basin area, sq km
A	Mune River at Ubon	105,110
B	Chee River at Yasothon	44,630
C	Chee River at Maha Sarakham	28,420
D	Chee River at Khon Kaen	10,390
E	Pong River at dam site	11,730

generally prevailed for 36 days or more. Differences between maximum and minimum water levels (gage heights) are shown to illustrate the problems that will arise in establishing intake points in the dry season. These differences are physically expressed in very steep banks in most places. The average bank height for all stations is 7.6 m; disregarding the station with no report during the normal highest water period and the three with drainage areas of less than 550 sq km, the average is 8.9 m; removing the Mekong stations makes the average 8.0 m or about 26 ft. Field observations would indicate that steep banks of this order of magnitude can be expected throughout the Northeast.

Surface-Water Losses

The two factors continuously working against surface-water accumulation are infiltration and evaporation, of which the latter is by far the larger and seemingly the more difficult to control. Because most water impoundments of the Northeast, natural or man-made, are necessarily very wide in relation to their depth, maximum surfaces for these two loss factors are presented.

The average net evaporation loss per day in the dry season from tanks, based on several years' testing by the Irrigation Department, was 4.8 mm and ranged from 4.8 to 5.3 mm/day (Ref 14, p 8). Molagool[16] suggests that reservoir evaporation amounts to 85 percent of the potential evapotranspiration of a locality; using a coefficient of 0.85 for reservoirs the net would be an average of about 4.3 mm/day. Evapotranspiration losses for the total period January–March compared with infiltration losses are shown for 37 reservoirs in Table B6. Monthly and annual evaporation data for 10 meteorological stations are listed in Table B7.

Evaporation Retardants. Recent development in the US suggest that the use of monomolecular long-chain alkanol films might have considerable promise in reducing evaporation losses in the Northeast. Wind is the uncontrollable variable having greatest effect on use of such films. Economical methods have been described (Myers,[18] 1965) that work well on ponds and small reservoirs. Tests showed evaporation was reduced 40 percent despite heavy films of dust and algae on the water. LaMer[19] (1965) describes a different implementation system, economical on large reservoirs if wind velocities are less than 24 km/hr (15 mph), that would not even need replenishment if wind velocities were less than 3 km/hr (4.8 mph). As average wind velocities in the Northeast are apparently less than 5 mph (Table A5) and winds in excess of 15 mph are infrequent (Fig. A5) these methods may offer considerable promise.

Lining. Seepage or infiltration losses in surface-water bodies depend basically on the permeability of the underlying soil, but depth of water (hydrostatic pressure), depth to water table, and soil and water temperatures also exert influence, as does the age of the impoundment structure. Losses can be prevented or greatly reduced by lining the water-holding structure or its most permeable parts with an impermeable or semi-impermeable material. Concrete, asphaltics, plastic, and compact clay can be used for this purpose. A number of factors are considered in determining the advisability of lining, particularly in canal systems. Usually the most important factor economically*

*Lining has a water-quality value also. The increased flow rates and lack of vegetation and ponding aerate the water and reduce some forms of bacteria and insect life.

TABLE B5

Stream-Measurement Data of Same Stations in Northeast Thailand

(Compiled from 1962 Hydrologic Data of the National Energy Authority[38])

River	Station	Coordinates: Lat, N	Coordinates: Long., E	Elev, m	Drainage area, sq km	Total run-off, millions of m^3	Discharge, m^3/sec: Mean	Max	Date	Min	Date	M
Mekong	Nakorn Phanom	17° 23.9'	104° 48.2'	131.1	373,000	207,000	6510	19,700	10 Sep	1320	14 Apr	9
Mekong	Mukdahan	16° 32.3'	104° 44.2'	124.1	391,000	232,000	7340	23,000	6 Sep	1310	15 Apr	10
Mekong	Kemarat	16° 4'	105° 12'	110[a]	427,700	—	—	—	—	—	—	18
Nam Mune	Pak Mune	15° 18.5'	105° 29.7'	87.1	117,000	—	—	—	—	—	—	12
Nam Mune	Ubon	15° 13.3'	104° 51.7'	105.1	104,000	29,600	937	3,950	16 Oct	13.7	14, 15 Apr	10
Lam Plai Mas	Ban Bost[b]	15° 13.1'	102° 39.3'	140.2	5,960	854.6	26.9	393	10 Oct	0.03	7-8 Apr	9
							19 Feb to 31 Dec					
Lam Dom Yai	Dej Udom	14° 53.9'	105° 4.8'	110[a]	3,340	1,890	59.9	313	23 Sep	0.30	15-17 Apr	8
Lom Dom Noi	Sae Falls	15° 12'	105° 26'	116.6	2,060	2,120	67.1	663	19 Sep	0.13	10 Apr	4
							(49.7, 1961)					
Nam Chi	Yasotborn	15° 13.1'	104° 8.5'	1[illegible]7.1	431,000[d]	11,700	370	1,930	10 Oct	3.60	23 Apr	10
							(12 yr 265)					
Nam Pone	Pong Neeb	16° 48.8'	102° 35.1'	155	12,000	2,780	88	1,080	22 Sep	0.19	4 Apr	15
							(5 yr, 71)					
Nam Pong	Nam Pong Bridge	16° 43'	102° 49'	151.3	13,120	—	—	—	—	—	—	14
Hnai Panieng	Ban Sang Sien[e]	16° 53.1'	102° 23'	176.1	1,830	—	7.48[e]	75.1[e]	15 Oct	0.10[g]	30-31 Dec	4
Lam Chern	Ban Song Kon[f]	16° [illegible]8.4'	101° 47.6'	100[a]	550	—	9.25[f]					
							(Oct–Dec)	656[f]	30 Sep	0.50[f]	24-31 Dec	11
Huai Nam Lai	Dam site	17° 29.2'	101° 46.6'	250.9	260	25.9	0.82	62.5	5 Oct	0.16	11-12 Jul	2
Huai Bang Sai	Ban Nong Agk Bridge	16° 38.4'	104° 42.2'	140[a]	1,337	—	—	—	—	—	—	6
Huai Bang Sai	Ban Kham Palai	16° 42.6'	104° 38.5'	141.4	1,240	686	21.8	482	6 Aug	0.05	30 Mar-4 Apr	8
Huai Bang Sai	Ban Pone Hai	16° 45.9'	104° 28.4'	150[a]	1,070	—[i]	—[i]	—[i]	—[i]	—[i]	—[i]	1
Nam Kam	Bantoug Bridge	16° 56'	104° 41.6'	120	1,700	—	—	—	—	—	—	9
Nam Pung	Ban Tam Hai Bridge	17° 4.8'	104° 15.4'	100[a]	1,070	230.53	7.32	140	4 Sep	0.03	2-4 Mar	5
Huai Huad	Ban Tao Ngoi	16° 58.5'	104° 10.2'	100[a]	636	—	—	—	—	—	—	3
Nam Pung	Dam site	16° 58'	103° 59'	253.8	297	77.6	2.41	44.4	5 Sep	0.01	29 Mar-4 Apr	2
Huai Keen	Ban Don Chiang Ban[j]	17° 15.8'	104° 9.5'	155.4	—	—	—	—	—	—	—	2

[a] Assumed.
[b] Installed 19 Feb 1962.
[c] Subject to backwater.
[d] Probably 43,100.
[e] Installed 8 Jun 1962.
[f] Installed 17 Sep 1962.
[g] Backwater from diversion dam.
[h] Backwater from Mekong.
[i] No report data 1 Aug–1 Sep.
[j] Started in Mar 1962.

A

TABLE B5

ırement Data of Some Stations in Northeast Thailand[38]

rom 1962 Hydrologic Data of the National Energy Authority[38])

Discharge, m³/sec					Gage heights, m					Suspended-sediments discharge, tons				
Mean	Max	Date	Min	Date	Max	Date	Min	Date	Diff	Max	Month	Min	Month	Annual
;10	19,700	10 Sep	1320	14 Apr	9.85	10 Sep	0.29	31 Mar-1 Apr	9.6	29,867	Aug	136.8	Apr	86,300,000
;40	23,000	6 Sep	1310	15 Apr	10.02	6 Sep	1.10	15 Apr	9.9	34,248	Aug	115.4	Apr	98,500,000
—	—	—	—	—	18.48	7 Aug	2.48	5, 18, 19 Apr	16	—	—	—	—	—
—	—	—	—	—	12.86	7 Aug	1.34	3-6 Apr	11.5	—	—	—	—	—
ı37	3,950	16 Oct	13.7	14, 15 Apr	10.41	Oct	1.29	Apr	9	3,012,500	Oct	1719	Apr	6,730,000
26.9	393	10 Oct	0.03	7-8 Apr	9.72[c]	—	0.64[c]	—	9	—	—	—	—	—
b to 31 Dec														
59.9	313	23 Sep	0.30	15-17 Apr	8.73	Sep	0.46	Apr	8.3	—	—	—	—	—
67.1	663	19 Sep	0.13	10 Apr	4.61	Sep	0.55	Apr	4.1	172,705	Sep	27.34	Mar	390,000
.7, 1961)														
370	1,930	10 Oct	3.60	23 Apr	10.15	Oct	1.32	Apr	8.8	861,700	Oct	255.6	Apr	1,790,000
yr 255)														
88	1,080	22 Sep	0.19	4 Apr	15.45	Sep	0.65	Apr	14.8	—	—	—	—	—
yr, 71)														
—	—	—	—	—	14.06	22 Sep	0.74	9-11, 17-18 Apr	13.2	—	—	—	—	—
7.48[e]	75.1[e]	15 Oct	0.10[e]	30-31 Dec	4.63[e]	—	0.08[e]	—	4.6	—	—	—	—	—
9.25[f]														
ct–Dec)	656[f]	30 Sep	0.50[f]	24-31 Dec	11.4[f]	—	0.65[f]	—	10.7	—	—	—	—	—
0.82	62.5	5 Oct	0.16	11-12 Jul	2.04[g]	—	0.32[g]	—	1.7	—	—	—	—	—
—	—	—	—	—	6.35[h]	8 Aug	1.13[h]	14-15 Apr	5.2	—	—	—	—	—
21.8	482	6 Aug	0.05	30 Mar-4 Apr	8.13	—	0.11	—	8	379,694	Aug	59	Mar	663,000
—[i]	—[i]	—[i]	—[i]	—[i]	1.98	19 Jun 3 Aug	0.19	15-17 Jun 29-31 Aug 1-8 Apr	1.8	—	—	—	—	—
—	—	—	—	—	9.24	7 Aug	0.10	19 Apr	9	—	—	—	—	—
7.32	140	4 Sep	0.03	2-4 Mar	5.00	—	0.62	—	4.4	—	—	—	—	—
—	—	—	—	—	3.63	5 Aug	0.38	15 Jan-1 Feb	3.3	—	—	—	—	—
2.41	44.4	5 Sep	0.01	29 Mar-4 Apr	2.87	5 Sep	1.47	—	1.4	—	—	—	—	—
—	—	—	—	—	2.93	7 Sep	0.37	22 Mar-3 Apr, 15 May	2.6	—	—	—	—	—

D

TABLE B6

Reservoir Losses during January–March[a]

(In millimeters)

Reservoir	Province	Total loss	Evaporation	Infiltration
Huey Hert	Loei	462	350	112
Huey Mug	Loei	735	350	385[b]
Nong Bo	Udon Thani	403	347	56
Nong Kong Kwang		335	347	−12[c]
Nong Prajaksa		372	347	25
Nong Takai		380	347	33
Huey Tam Tieng	Udon Thani	1062	347	715[d]
Huey Pong	Sakon Nakhon	535	348	87
Poo Kratae	Nakhon Phanom	954	393	561
Nong Yati	Nakhon Phanom	400	393	7
Huey Lang	Khon Kaen	480	362	118
Sok Ruak		365	362	3
Huey Yai		400	362	38
Huey Sieu	Khon Kaen	360	362	−2
Wong Bor	Maha Sarakham	360	365	−5
Nong Kukard	Maha Sarakham	366	365	1
Jeiwei	Maha Sarakham	360	365	−5
Huey Po	Kalasin	362	365	−3
Bung Aram	Kalasin	371	365	6
Nong Majok	Kalasin	360	365	−5
Nong Phue	Roi Et	507	365	142
Nong Ya Ma	Roi Et	477	365	112
Tavachai	Roi Et	553	365	188[d]
Huey Tong Lang	Chaiyaphum	689	391	298[b]
Nong Platoa	Chaiyaphum	404	391	13
Buang Kraton	Nakhon Ratchasima	406	356	50
Bung Tonon Huk		330	356	−26
Nong Bung		568	356	212[b]
Bung Talma		436	356	80[b]
Nong Kok	Nakhon Ratchasima	450	356	94[d]
Nong Taman	Burirum	392	340	52
Nong Talok	Burirum	342	340	2
Snwanapa	Surin	391	340	51
Huey Nam Kam	Srisaket	648	372	276[d]
Huey Wang Dang	Ubon Ratchathani	428	372	56[d]
Setre Seni	Ubon Ratchathani	774	372	402[b]
Nong Lao Hin	Ubon Ratchathani	391	372	19

[a]From Molagool,[16] 1962. Place names spelled as in source document.
[b]Used for domestic water supply and for stock.
[c]Probably some seepage inflow.
[d]Unusually high infiltration rates indicated by sandy soil or seepage through impounding embankment.

TABLE B7

Mean Monthly and Mean Annual Evaporation Data for Ten Stations in Northeast Thailand[a]

(In millimeters)

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Aver. monthly mean	Annual	Period covered
Khon Kaen	99.4	121.4	143.9	143.8	145.0	100.0	77.7	77.9	50.9	68.3	89.0	72.0	100.0	1,189.3	1957–1960
Nakhon Ratchasima	98.3	102.0	117.0	114.3	85.5	82.0	77.5	70.5	49.1	59.4	73.1	87.4	84.7	1,016.1	1951–1960
Nakhon Phanom	90.9	90.9	101.9	113.3	75.8	53.7	44.2	40.0	41.8	69.2	81.7	87.0	74.2	890.4	1957–1960
Mukdahan	103.0	111.3	131.1	134.1	102.3	86.8	62.3	53.3	45.3	71.0	85.4	89.4	89.6	1,075.3	1957–1960
Loei	79.6	104.0	128.6	128.4	87.4	62.8	50.5	44.4	30.7	40.7	52.1	63.0	72.7	872.2	1957–1960
Roi Et	99.2	101.6	136.8	133.0	108.2	77.6	66.5	59.9	48.8	65.9	75.6	88.9	104.2	1,062.0	1958–1960
Sakon Nakhon	86.6	85.4	101.3	106.9	70.6	62.1	49.5	43.5	37.0	58.7	71.5	79.5	71.1	852.6	1957–1960
Surin	158.0	154.1	155.3	179.1	135.3	85.2	70.1	66.7	55.1	80.2	88.5	129.0	113.1	1,356.6	1959–1960
Udon Thani	89.4	94.7	123.6	119.0	77.1	62.4	57.8	49.7	47.2	62.0	37.2	82.0	78.4	902.1	1951–1960
Udon Ratchathani	109.6	106.9	120.6	110.7	90.6	68.8	60.9	55.1	47.3	70.5	91.2	98.2	85.9	1,030.4	1954–1960

[a]Based on Haworth et al,[23] 1966. Place names spelled as in source document.

is the value of the water saved by reduction of loss through seepage, soil erosion, and weed growth. The Royal Irrigation Department did not consider (Kambhu,[34] 1961) seepage losses from tanks a problem* since only 6 of the 37 tested (Table B6) showed a seepage loss in excess of "normal." Molagool[16] (1962) estimated that in the valley floors, where reservoirs are most likely to be built, infiltration would not exceed 5 mm/month because the soils would be less permeable. Such conclusions may be premature considering the number of existing tanks (140 at the end of 1965) and the number projected (1000).

By the end of 1965, 11 of the 140 tanks built by the Royal Irrigation Department had been lined, together with 32 km of irrigation canals. Apparently, concrete was the lining material used. Site-feasibility studies may help in decisions on lining of tanks and reservoirs, but they cannot be very effective in irrigation-canal works that cover wide ranges of soils.

Problems

Salinization. Infiltration losses may be acceptable or even useful in parts of the Northeast in recharging (raising) the ground-water resources, but there are many places where a general rise in the water table or even maintenance of it at the October level would create waterlogging and/or salinization with consequent injury to large areas of agricultural land. The salting of land has already occurred on a small scale adjacent to tanks and canals in some places in the Northeast (Moormann, personal communication, 1966) and could be a very significant problem in the long-range irrigation schemes being developed. Irrigation and drainage are inseparable, and the very low gradients of the present cultivated lands may make drainage as difficult as flood-water control. In many places little could be done to keep the water table down other than complete lining; even this might not have meaning in year-round rice cultivation with its requisite high water consumption. In many parts of the Northeast lining would thus serve a double duty in conserving both surface-water supplies and soils.

Terminology. The terminology used in water-impoundment structures in the Northeast has led to some confusion. Statistics produced by the various agencies concerned with water development may be misleading or erroneously interpreted. The major water impounder, the Royal Irrigation Department, now uses the term "ponds" to define its small rain- and/or ground-water-filled surface excavations (Fig. B5). It had no data on the total made but estimated that 6 or 7 were built in 1965. "Tanks" as used in the general sense by the department refers to earthen-dammed small drainages that retain the wet-season runoffs. Maximum heights are about 15 m. Israelsen[36] (1965) reports that of the first 97 constructed 40 were not more than 3 m (10 ft) deep and 17 were greater than 6 m (20 ft) deep. They were constructed primarily for irrigation purposes; only 29 of those built to date were intended for domestic purposes exclusively. The term "small tanks" is sometimes used by the department to define this class and "medium tanks" to define, in whole or part, the next-larger structures more commonly called "impounding reservoirs."

*The RID now considers lining necessary (M. L. J. Kambhu, personal communication, April 1966).

These are much larger stronger structures, holding deeper water. They are or will be located within the hilly and scarped borders and the Phu Phan Range. "Irrigation project," "diversion works," and "embankments" as used by the department are forms of water-control or utilization works whose main objective is to control or move, but not to store, the wet season's waters. They have little or no dry-season value.

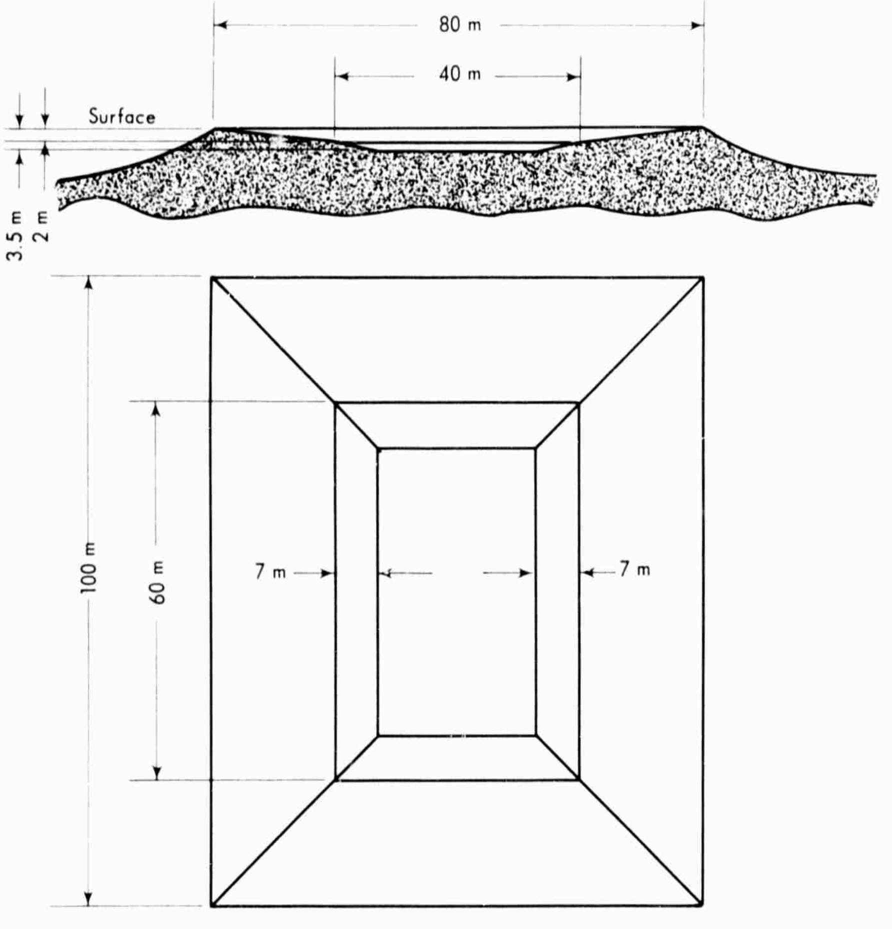


Fig. B5—Sketch of Typical Rain-Filled Ponds as Constructed by the Royal Irrigation Department

Design calculations assume an annual rainfall of 800 mm with total capacity of 6300 m^3 to the 3.5-m depth. Annual evaporation loss assumed at 2200 m^3. A fenced well drawing water from the pond may be included on the grassed inner slope.

The terms pond, lake, reservoir, dam, and tank, with or without modifiers, may be used by other agencies with different meanings. "Reservoirs" may mean all surface-water storages; "tanks" may mean only elevated metal storages.

Major Programs

As early as 1947 the Royal Irrigation Department recommended the construction of small reservoirs and tanks as the least costly and most beneficial means of bringing new water to the Northeast for dry-season requirements and irrigation. Government concurrence and construction began in 1951 with AID and UN officials recommending that about 1000 tanks be built. Through 1965 the department has built or supervised the building of 140 tanks in the Northeast, with 5 to be built in 1966. In the 5-year period 1967–1971 it is expected that 72 more tanks will be built. All but 1 of the 133 tanks built through 1963 were in the six provinces bordering the south and southwestern portion of Northeast Thailand; the more sensitive changwads, therefore, initially benefited little (Table B8[39]). Later work has indicated more emphasis in the northeastern portions. The statistical data available on the first 133 tanks are tabulated in Table B8 and expressed graphically by year in Fig. B6. Approximate locations of all water-impounding dams and tanks completed, under way, and planned as of the end of 1965 are shown in Fig. B7.

In summing up it may be said that the design of dams and water-storage reservoirs is based on expected hydrologic conditions many years in the future, depending on the life expectancy of the hydraulic structures. It must be assumed that the future will follow the pattern of the past if the frequency of hydrologic events is to be predicted for long-range estimates. As has been indicated in preceding sections not enough, or enough good, data are available to consider any of these construction projects particularly well-founded. Domestic water-supply reservoirs can be easily constructed during the wet season to meet anticipated demands during the dry season, but the total area and capacities available for such purposes are limited by the environment. It is physically impossible to capture and store more than half the Nam Mun Basin's mean annual water supply. Additional supplies from the proposed Pa Mong Reservoir on the Mekong are the only possible source, and although a large area would be served by gravity feed, assuming a water-level range of 220 to 240 m, pumping would be required to service much arable land at higher elevations.

Summary

The surface waters of the Northeast during the critical dry period represent an important input to its resources, but at present they must be considered more in the context of long-term effects on economic development than as local sources of domestic or military supply. The primary effort of the government in this field is in the development of reservoirs and related irrigation schemes. As these are completed and if concomitant village distribution systems can be constructed, domestic-water-supply demands peripheral to them can be met. However, their areal extent, and therefore effect, can never be great, since such dams and related works must be practically and economically restricted to favorable terrains commonly lacking in the Northeast.

The rather limited development of "ponds" by the Royal Irrigation Department or the similar structures constructed at village levels with or without the aid of other government agencies have much wider distribution, but in most places their current and planned use is for stock watering. Such structures, as well as deeper natural water-filled depressions and small streams,

TABLE B8

Tanks in the Northeast Region[a]

(Completed to the end of 1963 and under construction in 1964)

Project	Province	Capacity, millions of m^3	Irrigable area, ha	Cost, millions of bahts	Construction year	
					Started	Completed
Tanks Completed to the End of 1963 (133)						
Nong Kok	Khorat	2.083	142	1.090	1951	1953
Bung Ta Lua		1.102	—[b]	0.560	1951	1951
Huai Yang		5.540	544	2.761	1951	1956
Bung Katon		7.656	164	0.807	1952	1952
Bung Thanonhuk		0.809	65	0.340	1952	1952
Nong Nae		0.696	—[b]	0.767	1953	1954
Nong Bua		0.234	—[b]	0.060	1953	1953
Huai Nam Kem		0.584	128	0.242	1953	1953
Huai Sakard		3.579	480	1.366	1953	1956
Nong Prue		0.062	—[b]	0.059	1954	1954
Bung Nong Ku		0.355	—[b]	0.375	1955	1955
Huai Ban Yang		6.520	816	5.695	1957	1958
Bung Bua Yai		0.500	—[b]	0.297	1957	1957
Huai Sub Wai		0.080	—[b]	0.690	1960	1960
Tarn Asok		3.602	480	3.997	1960	1960
Takeong Pol		1.175	—[b]	1.800	1961	1961
Lam Channak	Khorat	23.445	1,600	5,826	1962	1963
Nong Thalock	Buriram	2.766	336	1.268	1951	1952
Nong Ta Moo		0.226	15	0.392	1952	1952
Huai Noi		1.201	130	0.884	1952	1953
Huai Talard		19.178	2,240	3.140	1953	1956
Huai Yai		1.315	168	1.755	1953	1957
Tung Loem		0.172	—[b]	0.196	1958	1958
Huai Kinoo		1.599	101	0.715	1961	1961
Huai Jorake Mak	Buriram	21.226	2,000	9.986	1962	1962
Nong Platao	Chaiyaphum	0.355	20	0.199	1951	1951
Huai Tong Lang		0.288	23	0.815	1951	1951
Basnrn		0.354	10	2.210	1952	1956
Hin Lub Meed		0.182	28	0.184	1953	1953
Nong Bhak Pang		0.147	—[b]	0.442	1959	1959
Huai Som Poy		7.647	800	4.502	1952	1961
Nong Bua Kok	Chaiyaphum	0.117	—[b]	0.500	1961	1961
Huai Nam Tieng	Udon	0.190	51	0.217	1951	1951
Sok Nam Kaow		0.467	237	0.485	1951	1951
Nong Boh		0.593	210	0.368	1952	1952
Nong Ta Kai		0.788	235	0.309	1952	1952
Nong Sam Rong		2.802	352	0.350	1952	1952
Nong Pa Ko		3.077	800	0.878	1953	1953
Nong Prachak		0.998	—[b]	3.952	1953	1953
Nong Khon Kwang		0.643	—[b]	3.439	1953	1953
Nong Onne		0.308	160	1.097	1953	1956
Nong Hua Tak		0.101	—[b]	0.136	1953	1953
Lam Pla Kaow		0.393	48	1.429	1953	1957
Sok Rang		0.430	38	1.173	1953	1957
Kud Ling Ngoh	Udon	5.440	1,216	4.368	1956	1961

Table B8 (continued)

Project	Province	Capacity, millions of m^3	Irrigable area, ha	Cost, millions of bahts	Construction year	
					Started	Completed
Huai Sai Swang	Sakon Nakhon	1.284	496	1.821	1952	1955
Pu Pek		2.708	640	1.561	1952	1956
Huai Pong		1.630	128	0.641	1952	1953
Huai Sai Kamin		2.402	768	2.464	1953	1956
Nong Bua	Sakon Nakhon	0.197	20	0.682	1953	1953
Nong Song Hong	Nong Kai	0.380	67	1.051	1951	1952
Huai Plew Ngueg	Nong Kai	2.752	1,328	1.353	1952	1956
Bang Puan	Nong Kai	10.071	960	4.740	1956	1962
Pu Kra-Tae	Nakhon Phanom	0.203	43	0.782	1951	1951
Rong Ka Bow		0.348	191	0.471	1952	1953
Nong Yart		6.797	792	0.646	1953	1953
Huai Chieng Yuen		0.344	224	0.613	1953	1953
Huai Som Hong		2.424	1,600	2.117	1956	1958
Bung Mor		0.343	—[b]	0.339	1957	1958
Huai Sri Khun	Nakhon Phanom	1.806	1,056	1.787	1956	1959
Nong Bua	Maha Sarakham	2.549	712	0.982	1951	1956
Nong Boh		0.967	352	0.700	1951	1951
Kang Loeng Chan		6.063	1,008	1.328	1951	1953
Exksattaya Suntorn		1.174	320	0.450	1952	1952
Nong Hai		2.022	160	0.470	1952	1956
Nong Kare Dum		1.276	240	1.029	1953	1953
Nong Ku Kard		0.368	72	0.721	1953	1953
Nong Wang Noi		0.385	—[b]	0.145	1953	1953
Rong Hua Chang		1.291	512	0.498	1953	1954
Nong Jock Kwang		1.284	1,744	1.426	1953	1956
Huai Chieng Kam		5.067	512	1.150	1953	1956
Huai Ka Kang		4.126	1,280	1.507	1956	1957
Huai Pra Doo		2.804	320	1.006	1957	1959
Nong Kra Toom	Maha Sarakham	2.528	400	1.469	1958	1959
Nong Mnen Than	Roi-Et	0.041	—[b]	0.110	1951	1951
Nong Ya Mah		2.117	512	0.700	1951	1952
Nong Pue		4.178	192	1.185	1952	1952
Ta Watchai		3.013	752	0.146	1952	1952
Nong Wang		0.458	144	0.638	1953	1956
Huai Kud Dang		2.806	784	1.431	1953	1953
Nong Ta Jock		0:809	480	0.722	1953	1956
Huai Kud Kan		1.996	560	1.333	1953	1953
Huai Lang	Roi-Et	5.075	592	2.644	1958	1959
Nong Ma Jock	Kalasin	1.070	192	0.222	1951	1951
Huai Poh		2.465	458	0.720	1952	1953
Bung Aram		2.517	384	0.430	1952	1952
Nong Ya Mah		2.559	608	1.670	1953	1956
Nong Ban Sa		0.555	80	0.352	1953	1953
Rong Kaset		0.231	26	0.300	1953	1953
Huai Sri Dhon	Kalasin	5.890	1,760	2.008	1957	1959
Huai Wang Dang	Ubon	0.496	304	0.553	1951	1952
Nong Loaw Hin		1.673	160	0.432	1951	1951
Rong Nam Sub	Ubon	0.423	207	0.485	1952	1956
Huai Pho	Ubon	5.392	1,093	3.213	1952	1956
Sethseni	Ubon	0.183	—[b]	0.213	1953	1953

TABLE B8 (continued)

Project	Province	Capacity, millions of m³	Irrigable area, ha	Cost, millions of bahts	Construction year Started	Construction year Completed
Nong Chang Yai	Ubon	7.680	1,200	1.066	1953	1954
Nong Bua		0.127	—[b]	0.078	1953	1953
Sra Sming		1.011	347	0.819	1953	1954
Huai Muang		0.602	—[b]	0.943	1953	1954
Huai Wang Nong		1.260	48	1.475	1959	1959
Huai Pla Dak	Ubon	15.339	2,560	5.777	1957	1963
Suwanabha	Surin	1.073	376	0.662	1951	1951
Um Puen		3.728	1,072	2.544	1952	1956
Lung Pung		0.780	102	1.998	1953	1956
Nong Ka		1.053	91	0.619	1953	1956
Huai Raharn		1.103	64	0.543	1956	1956
Nong Sala		0.060	—[b]	0.081	1953	1953
Nong Ka Toom		0.540	—[b]	0.310	1957	1957
Ban Sakol		0.044	—[b]	0.115	1959	1959
Lum Phock		13.267	1,280	2.682	1953	1961
Loom Pook	Surin	0.364	27	1.264	1959	1962
Huai Nam Kam	Sisaket	1.010	95	0.710	1951	1951
Nong Sa-ang		0.876	19	0.571	1952	1953
Huai Sun		2.706	512	0.550	1952	1954
Huai Nam Kem		1.069	—[b]	0.817	1953	1953
Huai Poon		0.152	—[b]	0.074	1953	1954
Huai Klan	Sisaket	3.781	752	2.270	1956	1958
Huai Siew	Khon Kaen	1.167	544	2.134	1951	1951
Huai Yang		1.098	187	2.035	1951	1951
Sok Ruak		0.777	368	0.828	1951	1953
Tha Pra		1.579	—[b]	0.801	1955	1955
Huai Yai		0.481	221	0.211	1952	1953
Nong Navua		1.391	58	0.560	1952	1954
Kok Muang		0.188	256	0.866	1953	1954
Nong Hua Chang		0.209	—[b]	0.328	1953	1953
Sok Sam-ang		0.071	11	0.306	1953	1953
Nong Wang Noi		0.208	—[b]	0.340	1953	1953
Nong Chong Maew		0.120	—[b]	0.077	1954	1956
La Loeng Wai	Khon Kaen	2.800	560	0.886	1958	1958
Huai E-Lert	Loei	1.431	352	1.565	1951	1953
Huai Nam Wak		0.664	159	0.311	1951	1951
Huai Noi		0.426	112	0.436	1951	1951
Huai Nam Phow	Loei	1.364	781	2.308	1952	1956
Total		313.068	51,387[c]	162.800		
Tanks under Construction in 1964 (5)						
Huai Nam Boh	Sakon Nakhon	2.200	576	1.045	1963	1964
Huai Ang	Roi-Et	21.890	3,040	6.918	1963	1964
Huai Srai	Khon Kaen	2.355	176	2.510	1963	1964
Nong Tewaraj	Maha Sarakham	1.457	64	0.950	1964	1964
Huai Kilek	Nakhon Phanom	26.986	2,100	7.100	1964	1965
Total		54.888	6,256	21.523		

[a]Taken from "Water Resources Development in Thailand Completed to the End of 1963 and Under Construction in 1964," Royal Irrigation Department,[39] August 1964.[15] Place names spelled as in source documents.

[b]Used for domestic purposes only.

[c]Of this amount, 35,200 ha have been irrigated.

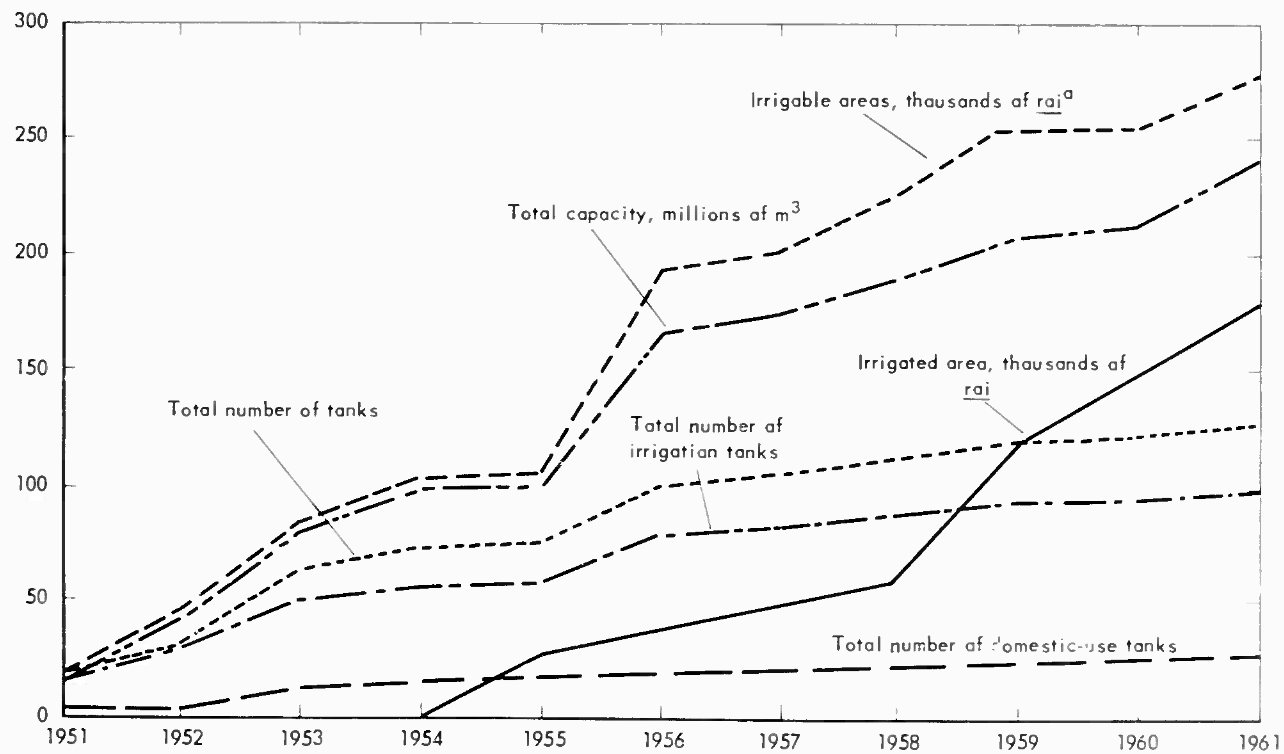


Fig. B6—Tank Irrigation in the Northeast, 1951–1961[b]

[a]A rai is 0.40 acre.
[b]From Royal Irrigation Department.[39]

Item	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961
Irrigation tanks	14	28	51	57	58	80	84	88	94	95	99
Domestic use tanks	2	2	13	17	19	20	22	24	26	27	29
Total number of tanks	16	30	64	74	77	100	106	112	120	122	128
Total water capacity, m^3	12,094,230	41,610,950	81,960,863	98,047,423	101,264,473	166,796,550	174,100,625	190,143,841	209,699,491	213,381,971	242,627,108
Irrigable area, rai	15,936	42,426	84,833	102,863	105,963	193,283	202,873	226,173	254,973	257,973	279,203
Irrigated area, rai					28,000	40,000	50,000	61,100	120,000	150,000	180,000

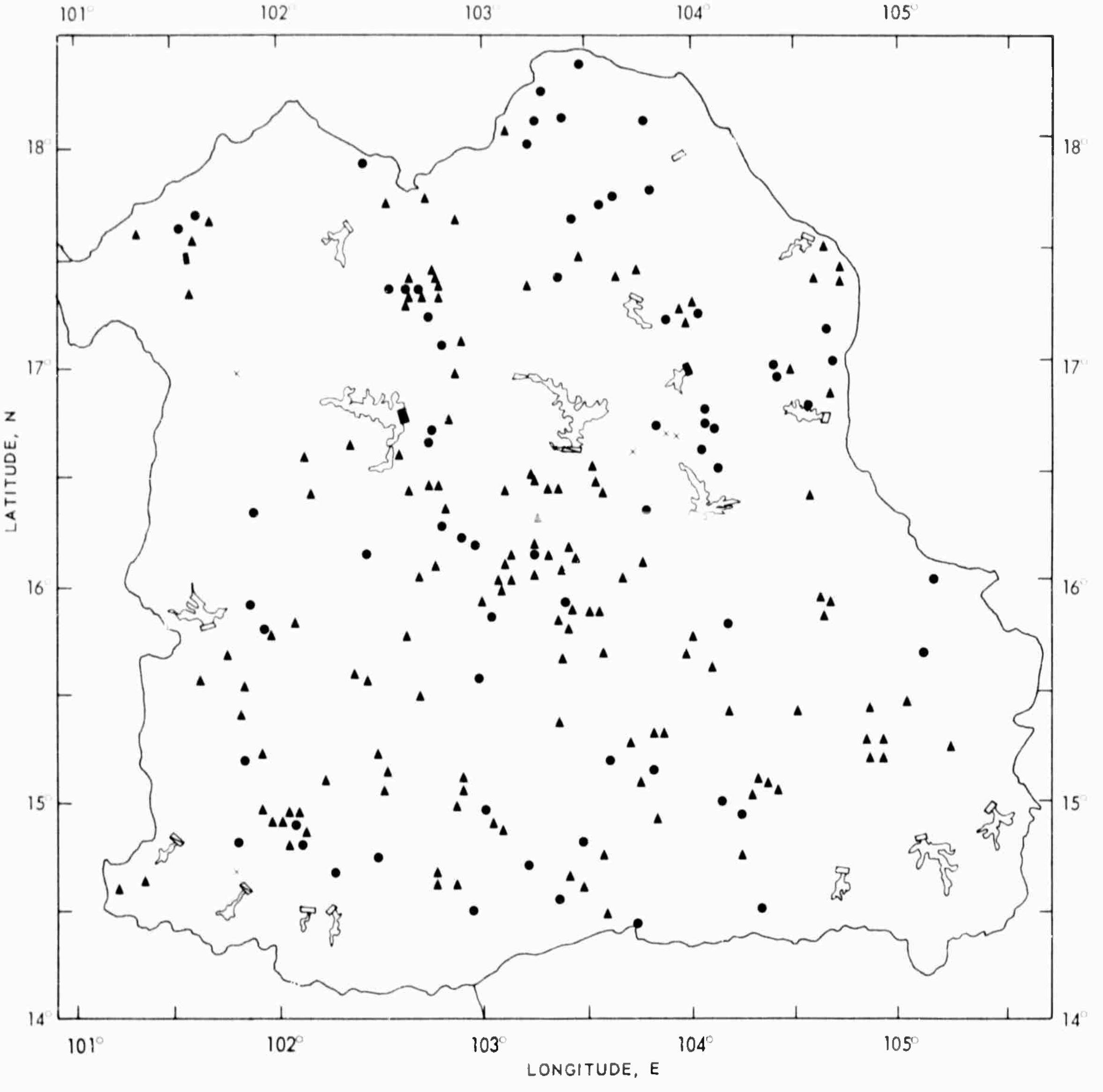


Fig. B7—Tanks and Reservoir Dams in Northeast Thailand Completed, under Construction, and Planned through 1965

Based on Statistic Section, Royal Irrigation Department, Thailand, 1966.[39]

Tanks	Reservoir dams
▲ Completed	Completed
Under way	Under way
● Planned	Planned

would provide emergency military water supplies, but their seasonal quantity characteristics, quality (see section "Quality,"),and location may not be known at planning levels.

GROUND-WATER RESOURCES

General

The ground-water resources of Northeast Thailand offer the greatest potential source for meeting domestic needs, civil and military, during the periods of water shortage—normally the dry-season months—because such sources (a) are least affected by droughts, (b) can ordinarily be located closer to where the need is, and (c) in general cannot be physically destroyed.

Ground waters are generally more desirable than surface waters for at least six other reasons:

(1) They are commonly free of pathogenic organisms and need no purification for domestic or industrial uses.

(2) The temperature is nearly constant, a great advantage if the water is to be used for heat exchange.

(3) Turbidity and color are generally absent.

(4) Chemical composition is commonly constant.

(5) Ground-water storage is generally greater than surface-water storage.

(6) Radiochemical and biological contamination of most ground water is difficult.

Furthermore from the standpoint of cost:

(1) Initial cost to develop ground-water supply is generally lower.

(2) Maintenance cost in production of ground water is less.

Ground water, or more broadly all the water beneath the land surfaces, is hydrologically distinctive because of the porous media in which it occurs and because of the influence of these media on its storage, flow, and chemical constituents. Far less is known about underground water than other phases of the hydrologic cycle because so little is known of the subsurface media in which it occurs.

There is disagreement on the nomenclature of various kinds of subsurface waters, and some terms are used in a contradictory sense (Ref 34, p 142). Figure B8[40] shows the early classic divisions wherein "ground water" refers to waters in the zone of saturation, i.e., below the water table. All rocks and soils in this zone into which water can penetrate are theoretically saturated with it. The reader should recognize that there may be more than one water table in an area. The higher water table(s) is(are) usually discontinuous, formed by local aquifuges or aquicludes and are referred to as "perched." In this diagram such perched water tables could occur any place in the zone of aeration. Some broad aspects of the environment relating to an understanding of ground water aquifers are discussed elsewhere in this report (see App A sections on Geology and Soils). Only those factors relating to inflow and outflow of such aquifers are reviewed here. Ground water in any stratum or basin is subject to a continuous process of natural and artificial discharge into springs, rivers, and wells and of replenishment through deep percolation of precipitation or spread water.

Water normally reaches the ground-water aquifers by slow infiltration or seepage through soil and rock. It can be natural, i.e., from rains and flooding, or be induced artificially. Infiltration has been referred to in previous sections but is redefined here because of its importance to ground waters. It is the passage or movement of water through the surface of the soil and is to be distinguished from ground-water flow. It decreases exponentially with time as soil becomes saturated and its clay particles swell. The rate of infiltration depends on such factors as the condition of the soil surface, density of vegetation, temperature, chemical composition of the water reaching the soil, physical properties of the soil (porosity, grain-size distribution, cohesion, etc), and intensity of rainfall.

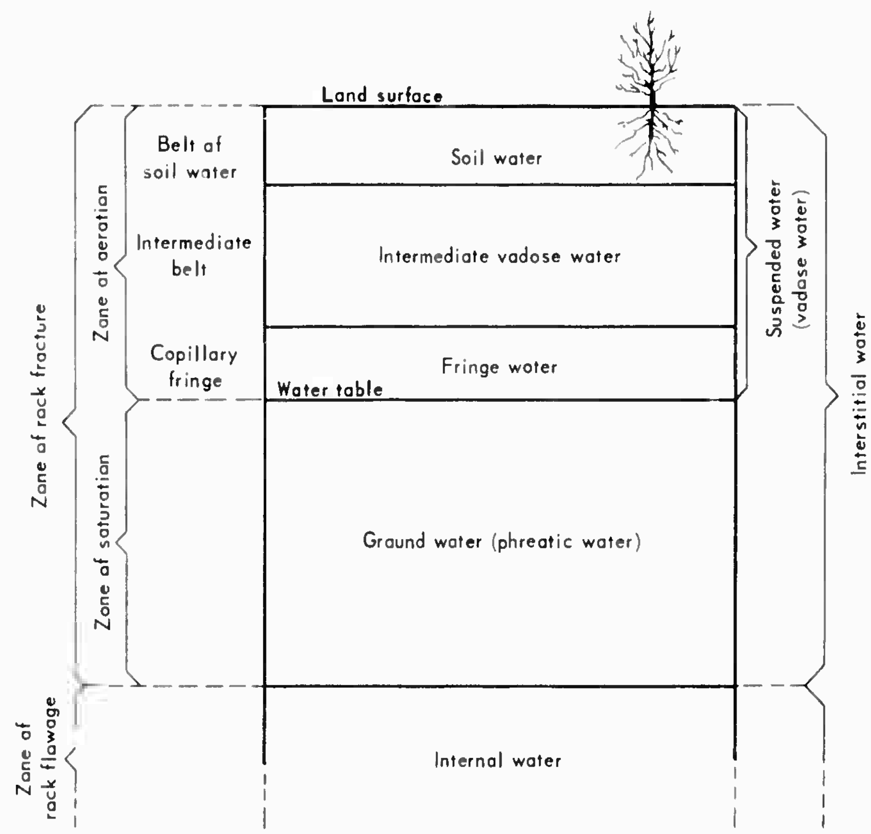


Fig. B8—Classic Divisions of Subsurface Water

From US Geological Survey water supply paper.[40]

Haworth[23] concluded that, for the Northeast, infiltration is greatest during the early months of the rainy season and is so complete during rains that there is little surface runoff before August. On the basis of his water-balance studies, Molagool[16] estimates that the overall infiltration rates amount to 20 mm/month during the wet season. For the remainder of the year there is no permanent loss to the ground-water zone.

In his long occupancy and use of the land, man has modified the natural ground-water balance by increasing inflow through the construction of impounding structures, canals, and irrigation projects. The net effect of padi construction is not as simple; certainly inflow is reduced by decreasing the soil permeability. Storage and outflow have been or will be modified by drainage projects and by artificial or induced cutting and filling. The use of wells is perhaps the most significant modification; a new well necessarily upsets any previous equilibrium, for all water discharged from the well must be balanced by a loss of water elsewhere.

Safe or sustained yields from wells in ground-water basins are not constant and must be revised with time. An accurate estimate requires the definition of a hydrologic budget between water quantities added and those removed. Typical components for such a budget are as follows:

Inflow: (a) Lateral inflow from adjacent ground-water basins

(b) Replenishment by deep percolation from rain water after deduction of evapotranspiration losses

(c) Replenishment by surface runoff from rivers and overland flow from nearby highlands

(d) Return flow from irrigation (about 30 percent of irrigation water)

(e) Artificial recharge (if any)

Outflow: (a) Pumpage, leading to a value of sustained yield

(b) Outflow to neighboring ground-water basins (natural discharge)

(c) Streamflow passing out of discharge areas; springs

(d) Evaporation from the water table

(e) Water exported from the basin (if any)

Some of these components are of course very difficult to determine with the best of circumstance and records, but in the Northeast very little is known about any of them in terms of long-range planning. Serious localized seasonal decreases in the shallow ground-water sources may be due as much to overuse as to the seasonal dropping of the water table.

Safe yields may be augmented by increasing recharge or decreasing natural outflow. Artificial recharge may have some potential in raising shallow-water levels in some parts of the Northeast and/or improving the deeper water tables where relatively impermeable laterites prevent deep seepage. Although the main purpose of artificial recharge is water conservation, quality is often improved by lowering ground-water hardness, and the soil itself has a high capability of removing and destroying the abundant microorganisms present in surface waters. In areas underlain by salty soils and waters, artificial recharge has adverse results, as discussed in the section "Surface Water."

The ground waters in the Northeast fall into at least two groups, based on availability and use. The first is commonly shallow enough to be reached by hand-dug wells but is more responsive to droughts. The second is deeper and beyond the reach of hand tools or in rock too hard to work by hand. It is not seriously affected by seasonal droughts. The first has been utilized for centuries; the second only significantly in the last decade. Both are discussed here in the context of development by dug or drilled wells as if they were separate entities, but it should be understood that the boundary separating them is arbitrary.

Shallow Ground-Water Resources

The shallow ground-water resources, meaning those in the present alluvial plains, valley bottoms, and the unconsolidated materials of terraced interfluves, whether representing the true or perched water tables, have been and probably will be a major source of water for domestic purposes in the Northeast. Some dug wells in alluvium are still producing all-season village water supplies after 2000 years (LaMoreaux,[10] 1958, p 29).

The shallow sources have generally been referred to as "those reachable by hand digging," although bored wells, those excavated with hand or power augers, might also fit into this class. Resources thus considered may range to depths of 100 ft. LaMoreaux[10] in one of the few published surveys of dug wells in the Northeast estimated that dug wells ranged from a few feet to not more than 50 ft in depth. Military planning maps (Johnson,[29] 1964; PACOM,[28] 1960–1961) concerned with water resources generally use 20 ft as an arbitrary limit for dug wells. Regardless of the exact depth of the lower boundary a vast reservoir of shallow ground-water resources exists in the Northeast. The problem of its ultimate use and development may be related mainly to health factors (high biological contamination of dug wells) and the lack of understanding of its potential productivity through lack of geological research on the unconsolidated materials.

Early work in the Northeast[10] pointed out the potential of the alluvial material in supplying shallow ground-water resources and suggested that more basic work be done on this potential supply, including a full inventory and observation of existing shallow (dug) wells. Later ground-water workers tend to write off these shallow sources as being too likely to dry up or basically unsanitary. Also it is likely that much confusion has arisen from the tendency to correlate methods of development (dug vs drilled wells) with depth or terminology of the aquifer.

The DMJM[9] (1961) report on drilling results found most perched waters less than 50 ft deep in their extensive "shale province" to be of the best chemical quality but suggested most would be biologically contaminated, although apparently none was so analyzed. Haworth[23] (1966) in summarizing all previous drilling work but essentially referring to the areas of alluvium as indicated on the geologic map (Fig. B7), indicated that alluvial ground waters were mostly of poor quality (chemical) although having the highest yields and specific capacities (sand and gravel aquifers) of any materials except limestones.

Khan[41] (1963) in a study of wells in Ubon Ratchatani Changwad found that most dug wells had water levels at about 3 ft in depth at the end of the rainy season but that some were as deep as 12 ft. Water heights were reported as varying with time of year. Some went dry in April or May, but the actual depths of wells were not given. Observations of this nature seem to constitute the bulk of available knowledge on the lowering or drying up of shallow ground-water resources.

Several government agencies are assisting at the village level in the extension of dug wells primarily through the development of biologically "safe" domestic supplies. Those contacted apparently had had no real technical guidance as to where best to locate such supplies or as to best methods to use in their development. At least one likely existing source, the Soils Survey Division of the Department of Land Development, has apparently not been utilized

to date. It is apparent that a comprehensive study of shallow-water resources would be most valuable in planning and developing village water supplies in the Northeast. An integrated approach is suggested because the survey and mapping work required seems beyond the current staffing capabilities of any one agency. Such a study could make use of the changwad-hydrogeological-mapping program of the Department of Mineral Resources Ground Water Branch and the comparable soils-mapping program of the Soils Survey Division to provide insight and guidance on the most likely productive local areas. Agencies of the Departments of Health and Local Administration now working on dug-well assistance programs or other government agencies working on aid programs at the village level could contribute their knowledge on well locations and determine measured data on seasonal depths of water levels (or instruct the villagers in maintaining such records).

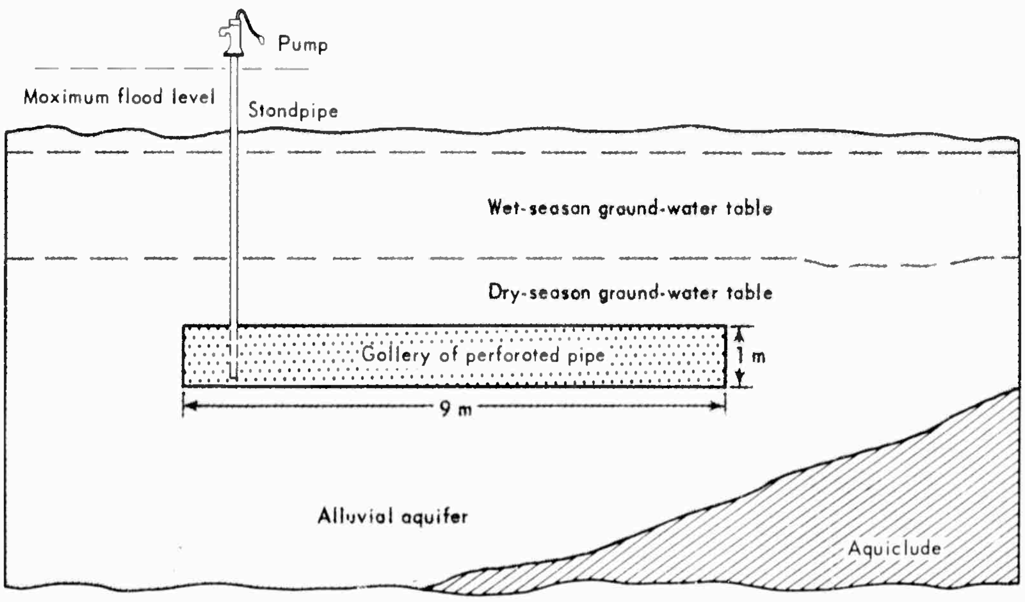


Fig. B9—Horizontal Infiltration Gallery

Dimensions of gallery and spacing of perforations vary with local conditions.

Development of these shallow ground-water resources, however, need not necessarily await such projected comprehensive studies. Existing wells can often be improved during the interim by the simple expedient of digging them deeper. On the other hand many of the water resources in the Northeast are located in aquifers that are thin and/or composed of soil materials that yield water slowly in wells (low specific capacities). Water quantities in such locations can be improved only by digging more wells (well fields) or by the use of infiltration galleries. The latter device seems not to have been used in the Northeast but offers promise. Such a gallery is in effect a buried nearly horizontal pipe full of holes into which water infiltrates, to be pumped out through a standpipe at the lower end (Fig. B9). The ends of the horizontal pipe must be sealed to prevent sedimentation and clogging, and the vertical

standpipe must protrude above the ground surface to a height above flood level to avoid reverse flow. Emplaced in this manner and made 40 to 50 ft long an infiltration gallery can supply many times more water than a vertical well in the same location. Furthermore, security against contamination is aided by the natural filtration provided by the alluvial clays, silts, sands, and gravels packed into the trench around the perforated pipe as backfill. Inexpensive locally manufactured ceramic pipe 2 or 3 ft in diameter could be used with small-diameter holes (1/16 to 1/8 in.) formed at the time of manufacture as perforations. Hand pumps could be mounted on the standpipes.

Deep Ground-Water Resources

The search for and development of deep ground-water resources in the Northeast, although going back as far as 1906, did not involve any workable programs or real effort until 1955, when a large drilling program was established. Initially it was operated under the Royal Irrigation Department and Department of Health with technical help by the Royal Department of Mines. Reorientation and expansion of the programs first put the Department of Mines in supervisory charge of contractor work and finally, since mid-1961, in full charge of all the drilling. Much of the effort has been a joint Thai-USOM program. History of this work and its early results are available in many reports e.g., DMJM,[9] 1961; Haworth,[27] 1962. Although the program is continuing, the massive results of work accomplished through 1963 as well as some post-1963 results will be contained in the forthcoming monumental Department of Mineral Resources Ground Water Bulletin 2,[23] an early draft of which has been examined and referred to in many places in this document.

In the 10-year period 1956–1965 more than 1600 wells were drilled in the Northeast; 300 more were scheduled for 1966. Summary statistics were not available except for the wells completed by 1 January 1964. Data for these 1011 wells indicate that 71 percent yielded good water,* 8 percent were brackish, 14 percent were too salty to develop, and 7 percent were either dry or could not be developed for mechanical reasons (Table B9). Drilling occurred in all the changwads in the Northeast ranging from a maximum of 187 in Nakhon-rajasima (Khorat) to a minimum of 20 in Nongkhai. Results also varied areally: 93 percent of the wells produced good water in Nakhon Phanom Province, and only 33 percent were successful in Chaiyaphum.

For 768 water-producing wells (Table B10) at the end of 1963, 55 percent yielded less than 25 gpm, 26 percent yielded from 25 to 49 gpm, 13 percent yielded 50 to 99 gpm, and 6 percent yielded 100 to 1020 gpm. Yields varied from about 2 gpm to 1020 gpm with an average yield of 35 gpm.

The results of the drilling programs in the Northeast thus indicate that deep ground waters are available in most places. Only 43 wells† were abandoned as being dry or having insufficient water for production. The real problem was to avoid chemically contaminated water, mostly by sodium chloride (salt). The

*LaMoreaux (personal communication, 1966) indicated that many of the earlier drilled wells were for regional reconnaissance and stratigraphic purposes; the ratio of wells yielding good water would normally be higher.

†Eight of these are in the changwads of Petchabun and Lopburi and outside the Northeast as defined in this study.

TABLE B9

Well-Drilling Results in Northeast Thailand, 1955–1963

Total drilled wells	Producing wells, %						Abandoned wells, %					
	Total		Good		Brackish[a]		Total		Salt		Other	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent
1011	795	79	715	71	80	8	216	21	141	14	75	7[b]

[a]Suitable for stock watering.
[b]Four percent, 43 wells, were dry or had insufficient water for production; 3 percent were lost because of mechanical difficulty.

majority of the producing wells yield water from consolidated-rock aquifers, and these mostly from fractures, joints, and bedding planes rather than porous lithologic types. The typical alluvial aquifers, sands and gravels, accounted for only 19 percent of 742 producing wells, but these had the lowest average drawdowns and, if limestones are excluded,* the highest average yields and specific capacities.

TABLE B10

Available Production Data from 768[a] Wells in Northeast Thailand, 1955–1963[b,c]

Wells	Percent of total	Yield, gpm		Average depth to water, ft	Average drawdown, ft	Average depth of well or depth plug set, ft	Average specific-capacity range, g/ft/dd[d]
		Range	Average				
420	55	25	13	22	57	205	0.275
204	26	25–49	35	24	40	177	0.873
96	13	50–99	63	26	37	194	1.686
48	6	100–1020	162	22	34	167	4.782

[a]97% of total producing wells.
[b]For further information see discussion of Fig. B10.
[c]Based on Haworth et al, 1966.[23]
[d]g/ft/dd, gallons per foot of drawdown.

Relations of aquifer types to yields, specific capacities, drawdown, and depth to water are shown (Table B11) for the producing wells. Since producing wells are considered such on the basis of quality, these data represent only the usable aquifers. Almost all the wells that have been drilled into consolidated rock have been artesian although only 10 (as of the end of 1963) actually flow at the surface. The flowing wells generally have a low yield (average 6.4 gpm) and are from the Khorat Group of sedimentary rocks, and all but one are along the western margins of the Lam Mun Basin.

Haworth[22] (1966) produced a depth-to-water-level map based on the water levels measured in drilled wells, in essence a regional piezometric map. He cautions that (a) in no sense is the map to be construed as indicating water table conditions; (b) water levels in dug wells were not used; and (c) the measurements were taken at various times of the year, so that the levels indicated are generalized. This map is the basis for Fig. B10 and serves here only to indicate that natural or artesian waters, once located, are within easy pumping distance in much of the cultivated area in the Northeast.

No area-wide or aquifer-wide statements can yet be made as to the seasonal or pumping effects on the aquifers in the Northeast. Water-level recorders on observation wells are either too few or of inadequate duration. Based on the limited data to date it has been estimated (Haworth et al,[23] 1966) that water levels in deep wells reach a peak in the September–November period and are lowest from April through July.

The use of ground waters for irrigation purposes has not been the primary purpose of the drilling programs, as early yields were much too low. Of the

*Limestones occupy only a small fraction of the Northeast and are confined essentially to the higher wetter western portions.

TABLE B11

Relation of Aquifer Type to Water Levels, Yields, Specific Capacities, and Drawdown of 742 Producing Wells in Northeast Thailand[a]

Aquifer type	Wells		Average depth to water, ft	Highest–lowest water level, ft	Average yield, gpm	Lowest–highest yield, gpm	Average drawdown, ft	Specific capacity range, gpm ft dd	Average specific capacity, gpm ft dd
	Number	Percent of total							
Sand and gravel, sand, sandy clay	137	19	24	1–114	45	? to 222	29	0.055 to 47.8	1.527
Shale	214	29	21	5–95	24	1 to 130	40	0.013 to 44.9	0.597
Sandstone	91	12	21	+69–124	23	1 to 79.26	59	0.013 to 62	0.381
Siltstone	43	6	21	3–70	23	3 to 55	53	0.050 to 5.8	0.427
Shale, sandstone, siltstone (combinations)	158	21	22	+7–80	32	2 to 1020	48	0.017 to 57.7	0.659
Limestone	28	4	37	6–99	86	2 to 458	34	0.035 to 66.6	2.566
Slate	8	1	22	6–45	37	11 to 69	74	0.164 to 1.24	0.496
Granite-diorite	16	2	27	7–60	35	5 to 158	59	0.060 to 5.8	0.593
Basalt-andosite-rhyolite-trachyte	27	4	35	5–117	36	1.8 to 157	87	0.006 to 14.7	0.413
Miscellaneous silt (shale?), clay	20	3	13	7–37	21	2 to 61	43	0.0272 to 20.7	0.484

[a]Based on Haworth et al. 1966.[23]

144 wells with yields over 50 gpm, 48 yield 100 to 1000 gpm (averaging 162 gpm). The highest yields are commonly in sands and gravels, and it has been suggested that yields of 1000 gpm could be developed from many places if larger-diameter wells were used.

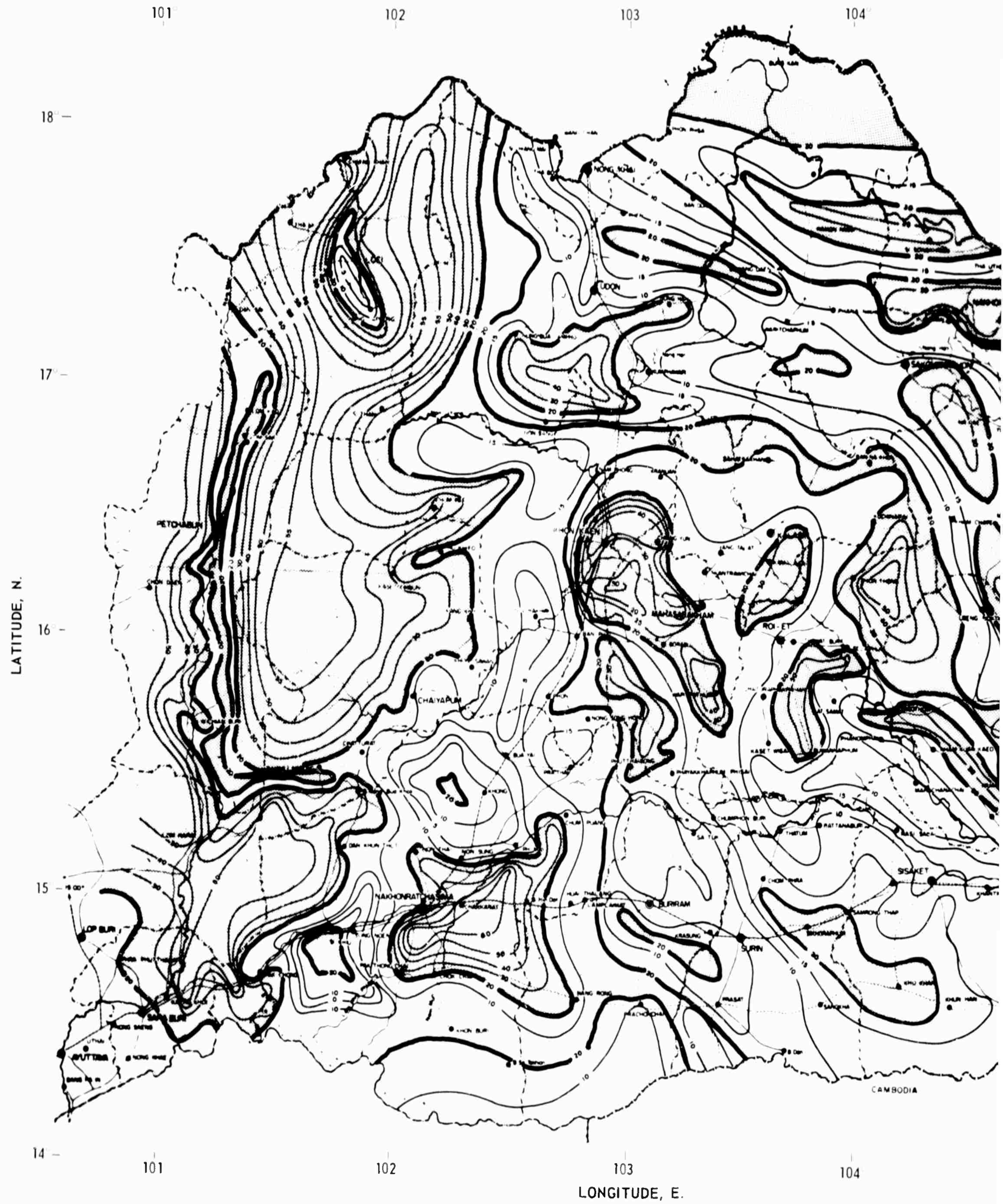
Deep ground-water resources are available in most places of the Northeast. Although most yields are not high they would easily satisfy, either alone or in well fields, the village needs. Such ground waters have the advantage of providing water essentially free of seasonal effects and, by the nature of well development, are generally safe from biological contamination. For these reasons they have been generally favored in water-supply programs in the Northeast.

Summary

There is no single way to evaluate all the ground-water resources in the Northeast but in sum total they must be immense. Ideally the development of a ground-water resource to meet a particular need is a separate study. Such studies demand adequate prior background research into all the environmental factors concerned but particularly into the types of consolidated (rock) and unconsolidated (soils) materials characterizing the area. This report expresses some of the problems, the status, and information deficiencies of the environmental sciences in Northeast Thailand. Nevertheless guides to ground-water resources can be prepared based on projections of hydrogeologists from the data available and could serve planners, civilian or military, at least until more quantitative information is developed.

In 1964 Haworth compiled a four-unit map of ground-water "availability" that defined availability on the percentage-probability basis of wells' locating sources of good water; it was in essence a quality-of-ground-water map. This map with units showing more than 80, 50 to 80, 15 to 50, and less than 15 percent good-water wells is reproduced here as Fig. B11 in its 1966 form (Haworth et al,[23] 1966). There are boundary differences between these two maps reflecting the new drill-hole information obtained, and it is likely that continued work will change them further. In general these differences have increased the probabilities of finding good water, although around Udonthani probabilities were somewhat decreased. Users of this map should recognize that the probability data and changes thereto were and may continue to be largely results projected from drilled wells, and the map does not necessarily reflect the quality of the shallow ground waters. Certainly in the major areas of high-chloride-bearing water, further described in the section "Quality," a substantial amount of the waters for domestic use must come either from shallow sources or surface-water impoundments.

Military ground-water maps (PACOM,[28] 1960–1961; Johnson,[29] 1964) express ground-water availability in a different format that may be more suited to the problem area to which this report is directed. The map units used by Johnson are basically defined by their geology and the respective inherent problems of locating aquifers and developing wells, all in the context of both quantity and quality information. They include all ground-water resources. This work, shown in reduced and abreviated form as Fig. B12, is already somewhat out of date, based on new drilling results, but could be brought up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PETCHABUN
KHON KAEN
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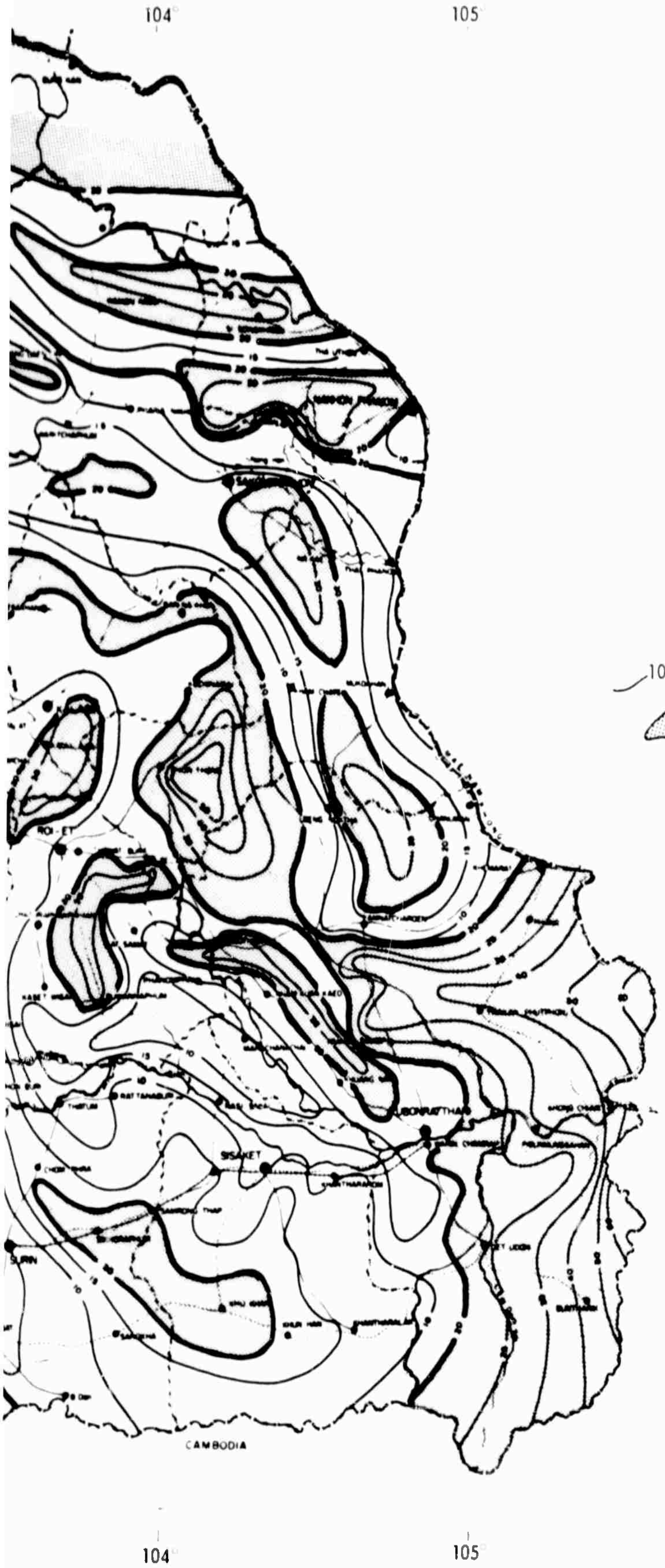


Fig. B10—Depth of Water in Drilled Wells

Based on Haworth et al, 1966.[23]

10 Water depth in wells after drilling. (Does not represent water levels in dug wells or deep water tables; most rock aquifers are artesian.)

Areas where water levels are greater than 20 ft deep.

B

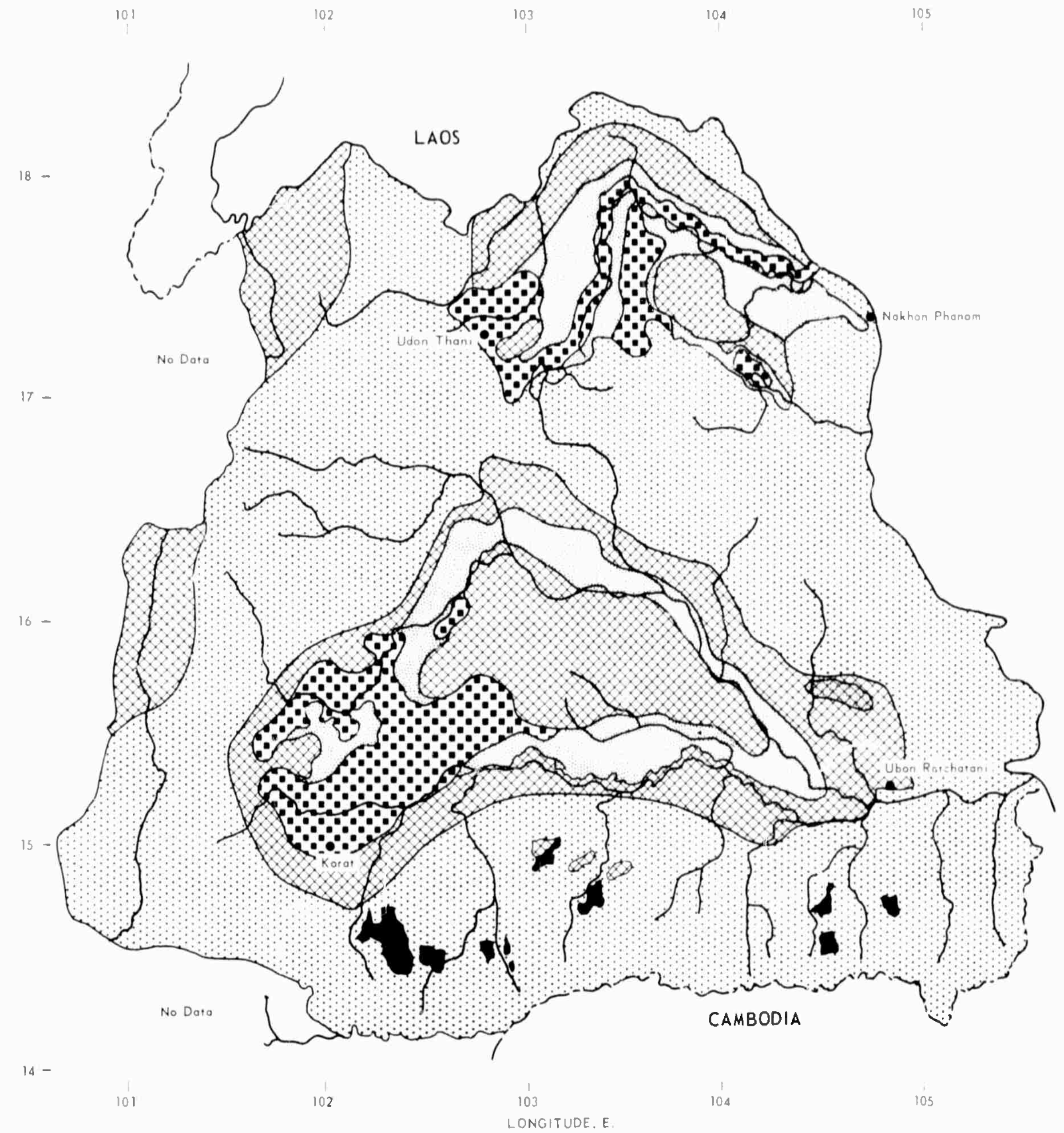


Fig. B11—Probable Occurrence of Potable Water in Drilled Wells in Northeast Thailand

Based on Haworth et al, 1966.[23] Place names spelled as in source document.

Percent of wells having good water (chemically potable):

> 80
50–80
15–50
< 15
B, basalt

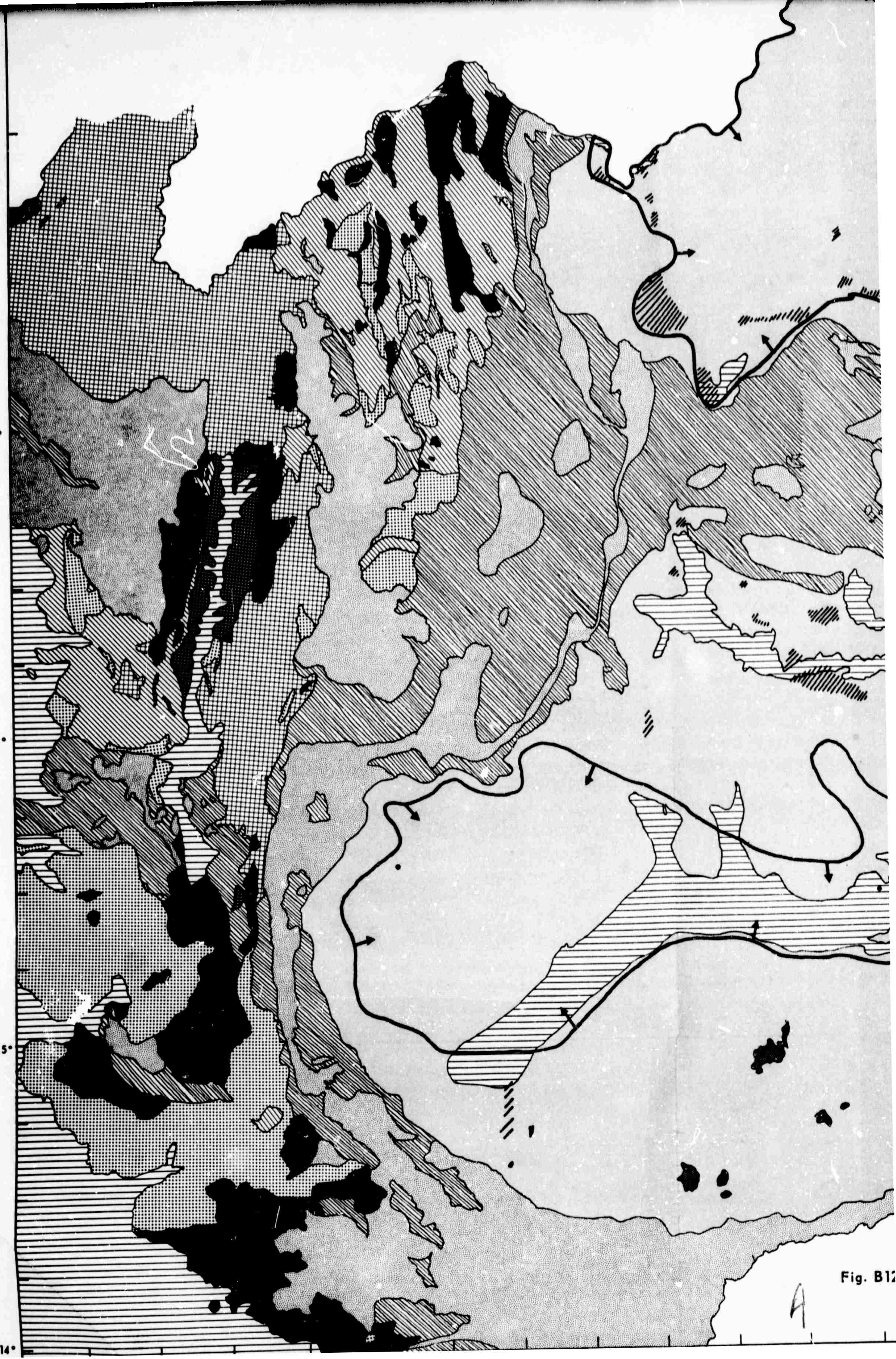
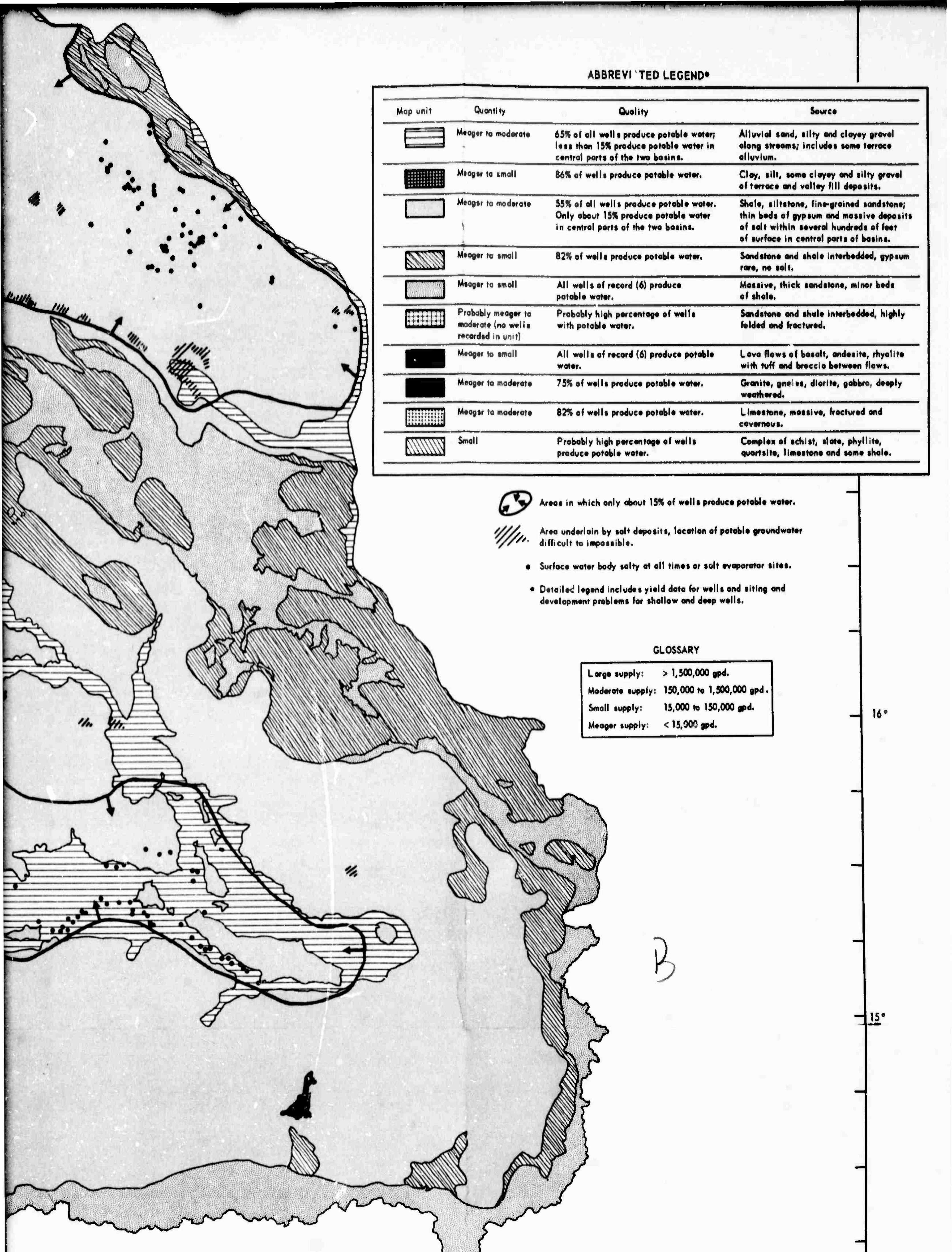


Fig. B12

A



12—Ground-Water Resources of Northeast Thailand
Based on Johnson, 1964.[29]

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to date by reference to the most recent work (Haworth et al,[23] 1966). The original Johnson report affords a particular advantage in that it locates and classifies the wells drilled on 1:250,000 maps.

QUALITY

General

Quality of water means different things to different people; that which is unacceptable to some may through long exposure be satisfactory to others. The farmers in the Northeast have long experienced waters so turbid or high in dissolved salts that clean well water is "flat-tasting" to them. Their principal objections to water quality have been to waters with a salty taste (from sodium chloride) and the odors associated with iron-rich waters. They have no basic concept of the relations of disease to water and little idea of how water can be biologically contaminated. Strenuous efforts are being made by the government (McQuary,[42] 1965), both educationally and physically, to provide "safe" water to the population of the Northeast, but the educational problem may be the more staggering. Other weighty problems obtrude; e.g., cures for schistosomiasis look promising, but of how much value are they in Southeast Asia if reinfection may occur at the next step?

This section examines the known quality data for dug wells, drilled wells, and streams and impounded surface water primarily as they affect human domestic use, although comment is made on other use where data are available.

Types of Contaminants

"Contaminated water" according to US Army Technical Manual 5-700[8] is any water that contains a harmful impurity that makes the water unfit for human consumption or domestic use. In this study two types of contamination are discussed: (a) natural chemical and (b) biological (not to be confused with chemical and biological warfare). Chemically contaminated waters are those in which the chemical content of individual elements or salts exceeds certain permissible limits Biologically contaminated water is here restricted to mean water containing organisms that produce such diseases as typhoid fever, paratyphoid fever, cholera, bacillary dysentery, common diarrhea (also produced by chemical contamination), amoebic dysentery, infectious hepatitis, and schistosomiasis. The turbidity, color, odors, taste of water, temperature, and acidity affect palatability and acceptance of waters for drinking and for some industrial uses but are usually not in themselves harmful. Quality as used here does not consider these factors per se because little quantitative information is available and they are not a substantive military problem (most are tolerable or easily correctable); they are mentioned only where they are incidental or affect the overall uses of water. The generally acknowledged limits to standards of quality for untreated water are given in Table B12,[43] largely based on US Public Health Service data. These data with respect to sulfate, chloride, and total dissolved solids are the basis for "fresh" water in Table B13, which relates further levels of concentration of these three chemical components in terms of possible human use and limitations, together

TABLE B12

Standards for Quality of Raw Water[a]

(Quantities are in ppm unless otherwise noted)

Components affecting quality of drinking water	General limits	
	Preferred	Maximum allowable
Biological components		
Biochemical oxygen demand (BOD)	3.5	7.5
Coliform	5000[b]	20,000[b]
Physical components		
Turbidity (silica scale)	250	—
Color (cobalt scale)	70	150
pH	5.0–9.0	3.8–10.5
Temperature, °F	60	90
Odor and taste	Not objectionable	Not objectionable
Chemical components		
Iron	0.5	10.0
Iron plus manganese	1.0	15.0
Chromium, hexavalent	—	0.05
Copper	—	3.0
Lead	—	0.1
Zinc	—	15.0
Arsenic	—	0.05
Selenium	—	0.05
Magnesium	125	—
Sulfate	250	1,000
Chloride	250	1,000
Fluoride	1.0	1.5
Nitrate	10	500
Phenolic compounds	0.001	0.025
Total dissolved solids	500	2,500

[a]From US Public Health Service and US Geological Survey (no date).[43]
[b]Most probable number (mpn)/100 ml.

TABLE B13

Drinking-Water Quality

(Rated in relation to three common limiting chemical components)

Designation	Sulfate, ppm	Chloride, ppm	Total dissolved solids (TDS), ppm
Fresh	250	250	< 400 (no taste) 400–500 (slight taste to some people)
Slightly brackish	251–500 (laxative effect)	251–400 (noticeably salty taste)	501–1000 (1000 ppm TDS, US Public Health limit)
Brackish	501–1000	401–1000	1001–2500 (2500 ppm TDS, strong taste but bearable)
Saline	1000	1000	2501–4000(limit of water chemically amenable to treatment)
Salty	—	—	> 4000 (chemically nontreatable)

with a “brackish” to “salty” designator. Table B14[44] ranks the same three components in terms of their possible effects in irrigation waters and is presented for possible order-of-magnitude interpretation. Comparable data unique to Thailand’s crops and soils were not available. It should be recognized that, unless there is excellent flushing of soil, high ion contents will continually build up within the soils. In a rather oversimplified way it has been suggested (Kambhu,[35] 1961) that if this happens such salt-tolerant crops as coconut, pomegranate, chili, and onions could be grown.

TABLE B14

Water Quality for Irrigation Use[a]

Classification	Sodium, percent of total Na + K + Mg + Ca present	Boron (semitolerant plants), ppm	Chloride, ppm	Sulfate, ppm	Total solids, ppm
Excellent to good Suitable for most plants under most conditions	0–60	0–0.5	0–177	0–960	0–700
Good to injurious Harmful to some plants under certain conditions of soil, climate, and practice	61–75	0.5–2.0	178–355	961–1920	70–2100
Injurious to unsatisfactory Unsuitable for most plants under most conditions	> 75	> 2.0	> 335	> 1920	> 2100

[a]From California Resource Board, 1951.[44]

Ground-Water Quality

Dug Wells. As previously described, adequate data on dug wells in the Northeast are entirely lacking. However, although no real evaluation can be made of chemical quality, it can reasonably be assumed that almost all unlined wells are biologically contaminated and probably also the many unprotected lined wells.

The Department of Local Administration found that 92 percent of 41,939 dug wells tested in the Northeast were “unpotable” by their standards.[45]

In 1963 Khan[41] found that most villages in Changwad Ubon Ratchatani had only one well—uncovered, unlined, and with no storage or chemical treatment. In the entire changwad there were only 32 “safe” or “sanitary” wells (concrete lined and sealed from pollution seepage). These were generally deeper than 7 m (21 ft) and cost from 1200 to 1800 bahts, a price difficult for the people to raise. Further difficulties in the use of such wells were based on both the people’s inherent lack of mechanical ability and the pumps themselves. Pumps designed for a family of five to eight were being used to supply whole communities; no one was assigned responsibility for them and breakdown was common,

causing recourse to older unsanitary water sources. In one province 63 percent of the pumps in sanitary wells were not working. Studies by Blakeslee, Huff, and Kickert[46] (1965) of 40 villages in Udonthani Changwad showed an average of four wells per village with 70 percent having less than three. Of the 164 wells located, only 1 had been drilled and it was considered unusable on the basis of bad odor (iron?) and salty taste. Potability in their study was based on the villagers' tastes as to "salt and other contaminants" and not on chemical or biological analyses. It is not unlikely that by any reasonable standard all were biologically contaminated.

Chemical quality of the shallow wells reachable by digging can often be surmised by reference to their location. Those in the areas proved to have brackish to saline "deep" ground waters may frequently encounter salty-tasting water in low places. That such water is close to the surface in some places has long been evidenced by numerous salt effervescences during the dry seasons.

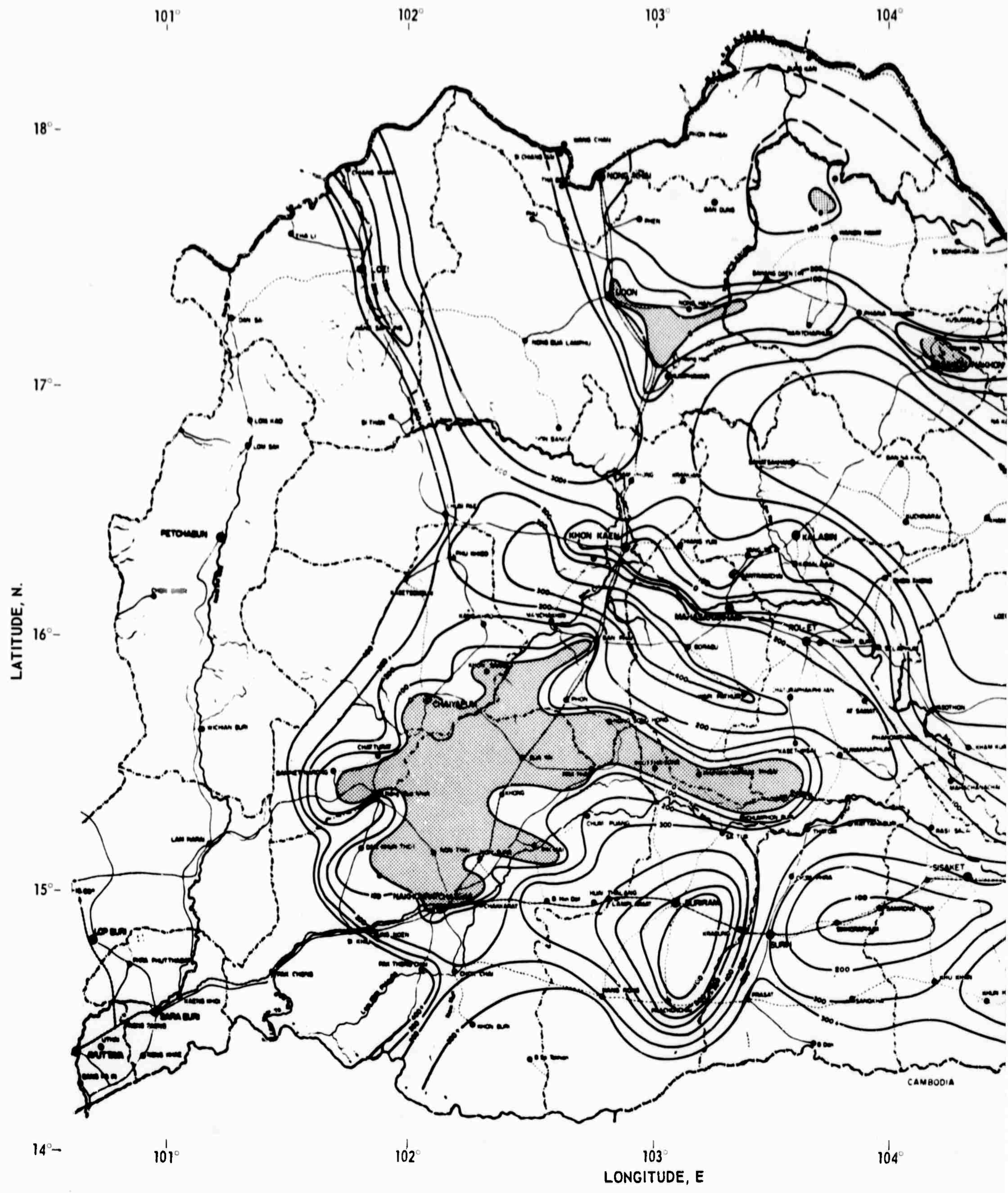
The use of airborne infrared sensing devices may have some application in the rapid outlining of the areal extent of shallow saline waters in the Northeast. Such techniques have indicated the feasibility, through ecological responses of vegetation and consequent tone changes, of detecting both brackish or saline standing-surface-water bodies and shallow ground waters. Cotton plants have indicated saline soils as deep as 4 to 5 ft.

The Haworth report[23] includes a map of depths to fresh water, reproduced here as Fig. B13, in which some large areas are included within a zero contour. Such small-scale maps cannot provide sufficient information for siting non-salty dug wells in critical areas. The best source of such information now seems likely to be the soils-mapping program, but this could and perhaps should be a joint project with the geological water-resources mapping.

Drilled Wells. The drilled-well program has yielded the only available chemical analyses of water quality over the Northeast. Biological contaminants are not analyzed in this program on the belief, generally understandable, that the deep water is biologically pure. This Department of Mineral Resources program includes periodic reanalyses, and some of its wells have improved in quality on pumping. There have been no saltwater incursions where most expected (at the town of Khorat) although elsewhere quality has diminished in some places. The department publishes the initial analyses of all its wells. These well-water analyses are the principal basis for isopachous maps showing hardness, chlorides, and total dissolved solids to be included in the department's forthcoming Ground Water Bulletin 2.[22] These maps provide the basis for Figs. B14, B15, and B16 in this paper.

Haworth[23] (1966) lists calcium, sodium, magnesium, iron, chloride, sulfate, bicarbonate, and silica as major constituents affecting the quality and use of ground waters in the Northeast, according to US Public Health Service standards (Table B12). On that basis three areas of objectionable drinking water were outlined:

(1) The central, northern, and northwestern part of Loei where sulfate is very high
(2) Northern Nakhonrajasima (Khorat), Chaiyaphum, and southern Khon Kaen where calcium, sodium, and sulfates are very high
(3) Southern Sisaket and southern Ubon Ratchathani where calcium, sodium, and sulfates are very high also


101°
102°
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CAMBODIA

A

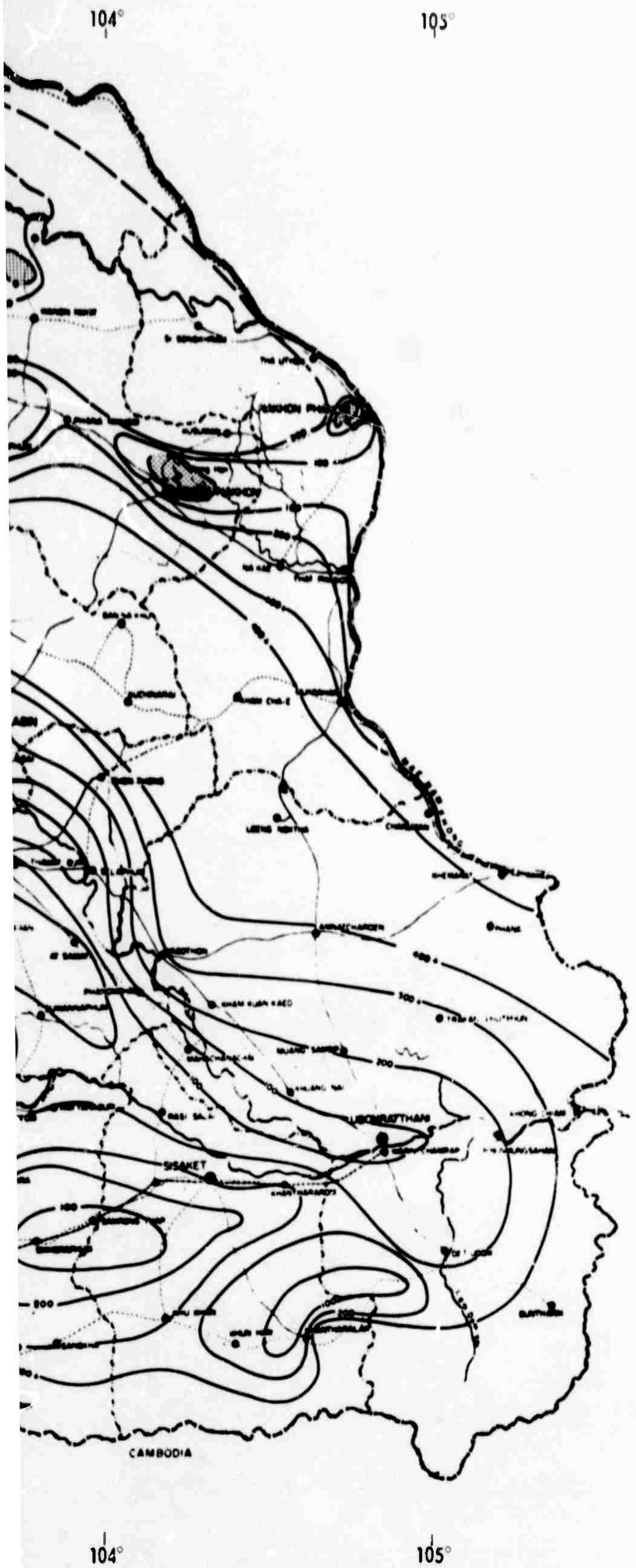

Fig. B13—Maximum Depths to Sources of Fresh Water

Based on Haworth et al, 1966.[23]

200 Maximum depths to fresh (chemically potable) water (based on drilled-well data); contours with plus signs indicate fresh water available at any depth

Solid areas indicate no fresh water was available from drilled wells

b

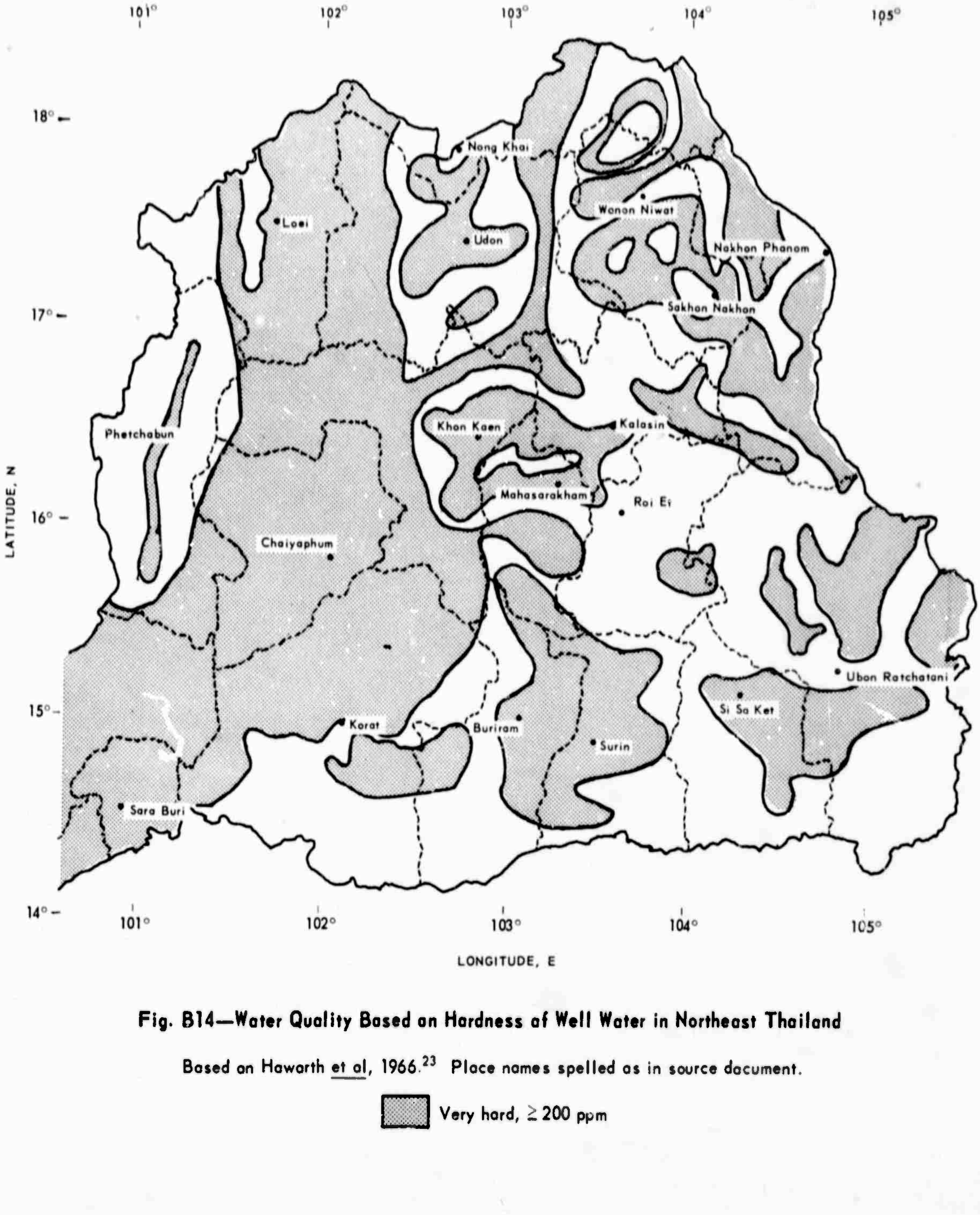

Fig. B14—Water Quality Based on Hardness of Well Water in Northeast Thailand

Based on Haworth et al, 1966.[23] Place names spelled as in source document.

Very hard, ≥ 200 ppm

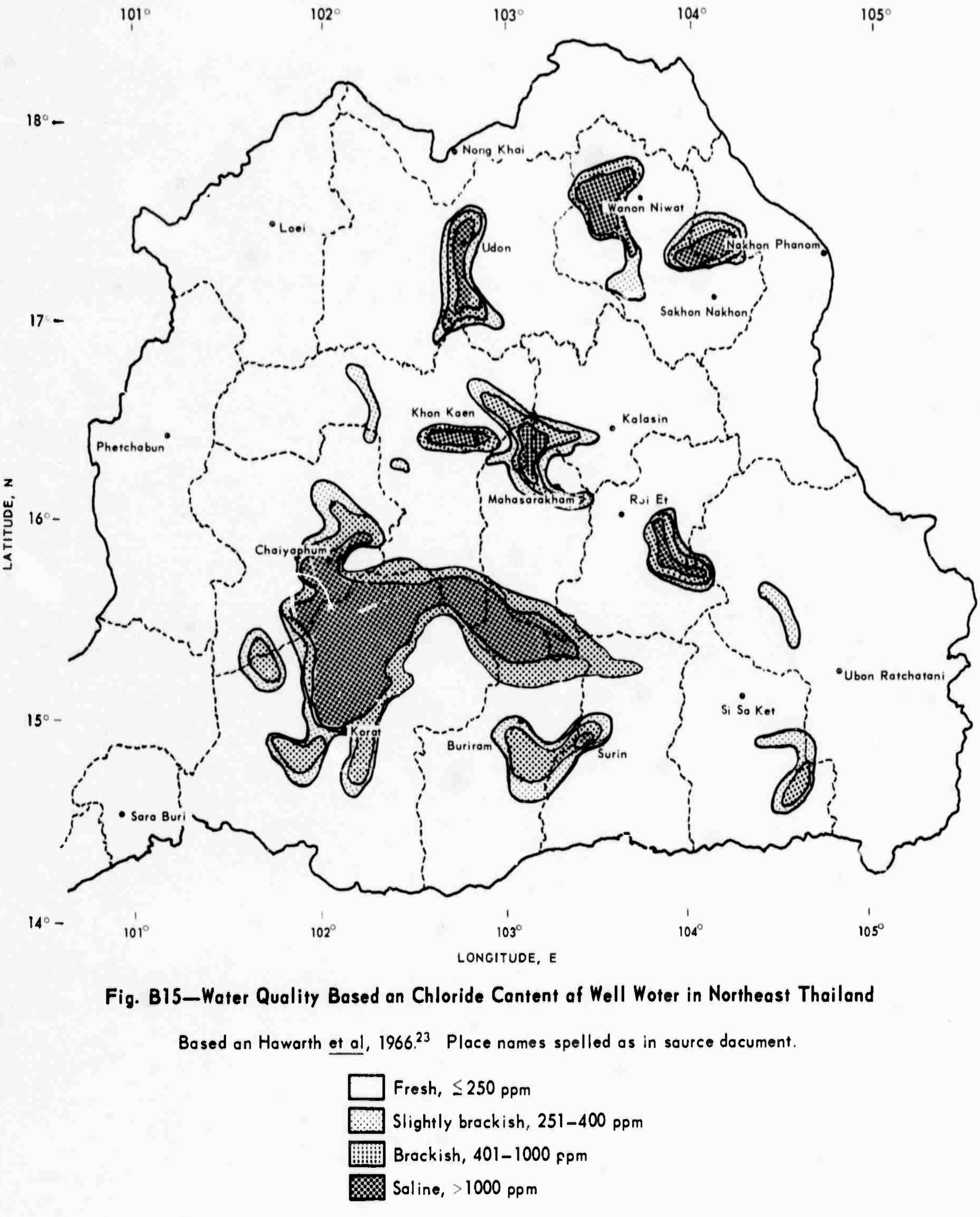

Fig. B15—Water Quality Based on Chloride Content of Well Water in Northeast Thailand

Based on Haworth et al, 1966.[23] Place names spelled as in source document.

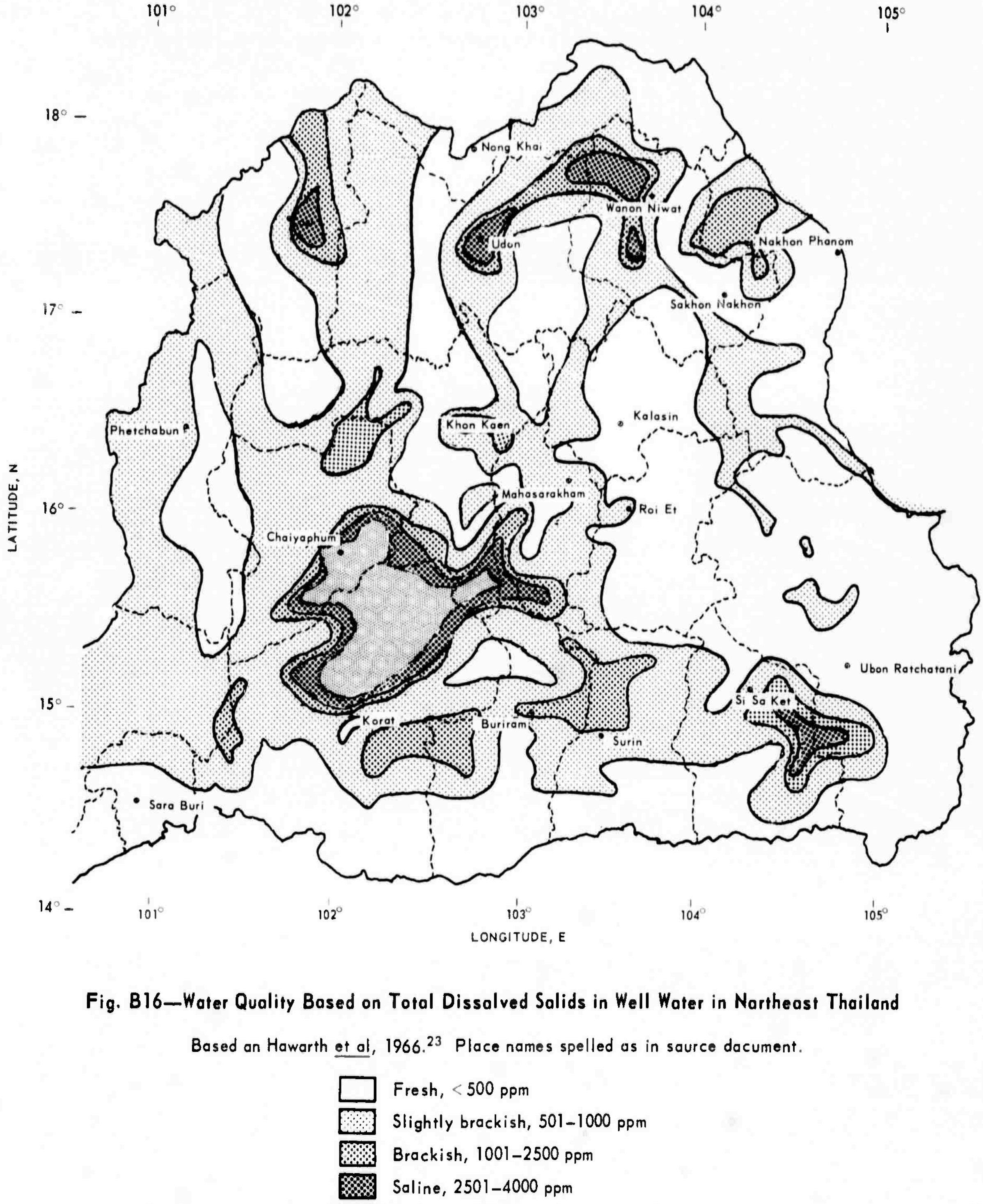

Fig. B16—Water Quality Based on Total Dissolved Solids in Well Water in Northeast Thailand

Based on Haworth et al, 1966.[23] Place names spelled as in source document.

- Fresh, < 500 ppm
- Slightly brackish, 501–1000 ppm
- Brackish, 1001–2500 ppm
- Saline, 2501–4000 ppm
- Salty, > 4000 ppm

Their report will describe the occurrences of the specific chemical contaminants, but they believe that only the very hard waters, high in iron and in particular salt (NaCl), have any real consequence with respect to the people's health or use of the ground water.

Sodium chloride, or common salt, is by far the most critical chemical contaminant of water in the Northeast. Salt-bearing beds (the Salt-formation of Fig. A7) underlie the principal populated places, the areas where surface soils are salty, and the areas where less than 15 percent of drilled wells produced good-quality water (Fig. B11), but this does not mean that all areas underlain by Salt formation yield bad water. Haworth[23] (1966) reports that only about 30 percent of the Salt formation contains salt in the upper layers and hundreds of wells have found fresh water at depths of 50 to 300 ft. The areas of high-chloride waters are shown in Fig. B15.

As indicated previously in the descriptions of the drilling program (Table B9) only 22 percent (221 wells) of the 1011 wells drilled up to the end of 1963 produced only salt-contaminated waters. Fresh water was found in 715, or 71 percent, of the wells. The Department of Mineral Resources reported (Haworth et al,[22] 1966) that 738 wells produced water usable for at least some purposes.*

TABLE B15

Average Salt and Total Dissolved-Solids Contents of Most Producing[a] Drilled Wells in Northeast Thailand[b]

Group[c]	Number	Percent	Salt (NaCl), average ppm	Total dissolved solids, average ppm	pH value
Good, < 100 ppm NaCl	661	90	15	536	—
Good to brackish, > 100 ppm NaCl	77	10	471	2815	—
All producing wells studied	738		63	774	7

[a]Producing wells are those that were developed because the waters were usable for at least some purposes. Figures represent 93% of developed wells as of 31 December 1964.
[b]Based on Hayworth et al, 1966.[23]
[c]Group designations as identified in Ground Water Bulletin 2 manuscript.
[d]About half of those having > 100 ppm have <250 ppm NaCl.

Of these 738 wells, 90 percent (Table B15) can be considered very low in salt contamination (average 15 ppm) although the total dissolved solids content of many would be considered marginal by Western standards or to persons unaccustomed to them. Regardless of their actual degree of contamination these high percentages of usable water represent a considerable change from the dim prospects generated by earlier drilling; this is due to drilling over a much more extensive area, more experience in drilling techniques and well development, and better knowledge of where to and where not to drill. Continued drilling should produce even higher ratios of good wells, and even in the "salty" areas should have fair results. In some critical areas, wells have been drilled to depths of 1000 to 2000 ft and nonetheless bottomed in rock salt. Suwit Watt-

* The presentation of statistical data on salt and total-dissolved-solids contaminants in Ground Water Bulletin 2[21] does not permit close correlation with the drinking-water-use limitations as shown in Table B13.

hanachan[24] (1964) in reviewing the possible origin of the salt deposits of Northeast Thailand indicates that thicknesses of more than 870 ft of rock salt were penetrated; he suggests that some of these thick salt sequences, e.g., around Nongkhai and Nakhon Phanom, are salt domes rather than basin deposits. The source of the salt may be the lower members of the Khorat series of rock formations. In such areas there is an apparent need for still-deeper exploratory holes, both to exploit a recognized fresh-water potential below the Salt formation and/or to provide needed geological information on its character so that the hydrological characteristics of the Northeast can be more fully known. Such wells would be beyond the capabilities of the current equipment and operating budget.

Considering quality only, most deep ground waters seem to be suitable for irrigation purposes and may have a positive value, if pH values are generally high, in reducing the soil acidity. Sulfate-bearing waters (Table B13) can be accepted by plants better than by humans. However, sodium and chlorides are critical in plant physiology, and chloride-bearing water still considered "fresh" to humans (+200 ppm) might be marginal in irrigation waters.

Although each industry has its own . .itations for water quality, it can be stated that those using deep-well waters in boilers will have scale problems in many areas, since these waters are generally hard (Fig. B14) and locally have high iron and silica contents.

Upper limits of total dissolved solids tolerated by various animals are shown in the accompanying tabulation.

Animal	Maximum amount of total dissolved solids tolerated, ppm
Poultry	2,880
Pigs	4,290
Horses	6,435
Cattle	10,000

On this basis only the center of the high-dissolved-solids area (Fig. B16) between Nakhonrajasima (Khorat) and Chaiyaphum would yield totally unusable waters. Elsewhere only poultry among the animals listed would have local problems, e.g., around Loei and Udon, northwest and southwest of Wanoniwat, and southwest of Udonthani. The daily water requirements of livestock and poultry are low (see accompanying tabulation) in comparison with the needs of crops (many irrigated crops take more than 400 liters of water to produce 1 kg of product); therefore animal raising may be economically more suited to the water-scarce areas of the Northeast.

Animal	Water requirements, liters/day
Laying hens	1.5
Sheep	6
Cows, per liter of milk produced	10
Horses	40

Surface-Water Quality

Dependable data on the quality of surface waters of Northeast Thailand are not available. From the biological standpoint it may safely be stated that all waters adjacent to or draining from human habitation are thereby contaminated. Collected rainwater, impounded waters in large reservoirs, and flood waters away from human occupation probably are least contaminated in about that order, but none can be considered "safe" without treatment. Such analyses as have been made are fairly recent, done either by the Department of Health directly or by health officers or teams operating within the changwads as a part of the emphasis on improving health conditions in the Northeast. No overall figures are available.

Few specific data are available on the chemical quality of the surface waters of the Northeast, but it is likely that they show considerable seasonal variation. A 1959 report by Kobayashi[47] on the quality of river waters in Thailand includes 12-month analyses (1956–1957) at five river stations and one lake station in the Northeast plus two on the Mekong. These analyses show a characteristically high content of sodium (Na) and chlorine (Cl) as a result of the high salt content (NaCl) at the drainage basins. Average contents for the five river stations for 1 year ranged from a high of 94.5 ppm from the Lam Chi near Khon Kaen to a low of 16.8 ppm at Chaiyaphum.

Chloride (and sodium) contents showed great seasonal range, being highest in the dry season, the maximum month varying by station, and lowest in the wet season, the actual low values seemingly dependent on local flooding. During the dry season the Khon Kaen station showed a high of 313 ppm and the Surin station 261 ppm from the Lam Mun. Lowest values from these two stations were 3.0 and 27 ppm respectively. Lake waters from Nong Han ranged from a low of 5.7 ppm to a high of 13.7 ppm chlorides during the year tested. The Mekong stations at Nongkhai and Mukdahan show highs of about 13 ppm chlorine in May and lows of 0.7 ppm in September.

The waters of the Northeast were low in calcium, ranging from 3 ppm in Nongharn to 10.9 ppm in the Lam Mun at Ubon in contrast to the Mekong, which had about 30 ppm calcium. Ranges in calcium and alkalinity (HCO_3) also show seasonal changes, being highest in April and lowest in July, but these changes, not as remarkable as the ranges in sodium and chlorine or corresponding with them in time, were nonetheless of a magnitude of 6 or 7 times.

Silica content also changes seasonally, but not as drastically, ranging from a low of 7.3 to a maximum of 14.3 on the Lam Mun. Therefore the scope of seasonal changes in the Northeast was on the order of

$$\mathrm{Na, Cl} > \mathrm{Ca, HCO_3} > \mathrm{SiO_2}$$

The total dissolved solids from these five river water stations, as determined by the average of 12 monthly (concurrent) samples is shown in Table B16. On this basis, plus analyses of water stored in various tank projects, the Bureau of Reclamation assumes that all the water likely to be so stored in the greater Lam Mun Basin would be of satisfactory chemical quality for irrigation purposes (Ref 15, p 24). Although this may be true for stored waters collected during the wet season, there may be local problems in high NaCl content if

water is used directly from the rivers in the dry season. Certainly there are too few stations, particularly on small streams, and too brief a set of records (1 year) to permit certainty about surface-water chemical quality.

TABLE B16

Dissolved Solids in the River Waters in Northeast Thailand[a]

(Average of monthly samples, July 1956–June 1957, in ppm)

River	Station	Ca	Mg	Na	K	HCO_3	SO_4	Cl	SiO_2	PO_4	N	TDS
Pao	Kalasin	9.0	2.1	23.6	4.2	45.9	0.3	35.5	15.7	0.00	0.31	119.3
Chi	Chaiyaphum	22.0	2.9	14.1	3.0	76.7	6.3	16.8	11.3	0.06	0.42	120.5
Chi	Khon Kaen	21.1	4.0	57.1	3.9	69.7	5.2	94.5	10.1	0.00	0.20	244.7
Mun	Surin	10.6	1.2	28.7	3.0	21.6	1.3	56.6	12.8	0.01	0.89	148.5
Mun	Ubon	10.9	2.3	40.0	2.8	42.4	2.0	61.6	10.8	0.00	0.28	165.2

[a]From US Bureau of Reclamation, 1965.[15]

The location, if any, of chemical analyses of the small ponds, tanks, and other surface-water impoundments was not established. It is known that in the areas where the upper layers of rock soil are salty the capillary rise of NaCl-saturated water, as previously stated, gives an efflorescence of salt on the surface and makes local ponds and soils saline and unusable. Johnson's 1964 map[29] (Fig. B12) does locate some ponds of high salt content, but probably there are many more.

The Royal Irrigation Department does not analyze the water in its impoundment structures and has no data on stream water quality but states, according to A. Imochan, Statistics Section, Royal Irrigation Department (personal communication), that all streams that contain water in the dry season have "good" water, even though the shallow ground waters along the courses of some (e.g., parts of the Lam Chi and Lam Mun) are known to have high salt content.

The Agricultural Chemistry Section, Department of Agriculture, makes chemical analyses of surface waters for irrigation purposes on an as-needed basis from samples sent to them by farmers. They neither compile data nor make further surveys based on the samples sent to them at the present time.

Summary

Programs to improve the domestic-water quality in the Northeast are as fundamental to its stability and development as are those to increase the quantity of water. The major contaminants are disease-producing organisms and common salt (NaCl). Other contaminants are either limited in extent, tolerable, or easily removed.

Until the advent of the current drilled-well program, it could justifiably be assumed that almost all surface and ground waters used by villagers were to some degree biologically contaminated. Ground waters, normally very low or lacking in such contaminants, were continuously polluted at or near the wells because of widespread misunderstanding of the nature of disease and its relation to sanitation. Energetic government programs in health and sanitation

coupled with construction of "safe" wells help significantly, but the problem is immense if only on the basis of the area involved. Moreover the quality of water in even the "safe" wells (and their current operational status) cannot be guaranteed.

Military operations superimposed on this environment, with contingent logistical demands and constraints, would require that water consumed be biologically purified if troop efficiency, health, and morale were to be assured.

Of the various chemical contaminants salt is by far the most serious since no economic method is available for its removal on a large scale. Although primarily a contaminant of ground waters, salt does contaminate surface waters in some areas but this appears to be of more localized concern. Salty ground water occurs widely in the Northeast, and at various depths, but in many places fresh ground water also occurs either above or below the salt-bearing water bodies. The drilling programs are rapidly defining the location, character, and relations of these dissimilar ground-water bodies, but there are areas where no fresh-water sources have been found within the depths drilled and surface-water impoundments may be the only potable source. In all such areas salt-contaminated water remains the most serious obstacle to the development of adequate civil water supplies. Any added military water requirement in these places, though temporary, would very likely be an unacceptable burden on civil supply. Although in most cases the military water supply could probably be obtained by short hauls from outside the salty-water areas, circumstances might nonetheless arise in which military units deployed would be forced to develop their own supplies. In spite of the fact that brackish water (potable but not palatable) is tolerable for emergency purposes, it might be expedient to determine the feasibility of construction and use of simple distillation devices.

Appendix C

BACKGROUND INFORMATION AND SCENARIO

BACKGROUND

Demography and Development

Approximately the size (65,000 sq mi) of the state of Illinois and constituting fully one-third of the Kingdom of Thailand, Northeast Thailand is the physical core of Southeast Asia. Commonly called the "Khorat Region," the "Khorat," or just the "Northeast," it is an underdeveloped area lacking much in the way of transportation, communication, and elemental needs of the population.

The Northeast largely lacks potable and palatable water and water-distribution systems. Throughout much of the region, roads adequate to the present needs of the people do not exist. Dry-weather roads do not in many places afford wet-weather passage except to water buffalo and large-wheeled carts, and thus transportation of both people and goods can be extremely difficult.

Although currently the object of considerable economic assistance, until recently the population of Northeast Thailand could be described as very poorly informed, inadequately nourished, not well housed or clad, medically deprived, and striving to extract a living from poor and depleted soils. Much of the population was not realizing even the modest living potential and productivity that were possible under the circumstances. Cleanliness, hygiene, and sanitation are still beyond the reach of many people who cannot be certain of even one uncontaminated drink of water let alone a dependable and continuing supply.

In general, work implements and tools are crude but sufficient if enough time and effort are invested in their use, but farm practices have evidently not changed much in hundreds of years. As yet the changes are not great, but as new agricultural techniques are introduced there is promise of improvement of crops and production. Clothes and tools are the principal wealth of some people in rural areas; the ownership of animals represents real affluence. Currency circulates poorly in outlying settlements and money is accumulated slowly if at all; many of the inhabitants have no ready way to acquire it. The state of development of much of the rural Northeast can be expressed perhaps as a conspicuous adjustment to a low-capital-flow economy. The remainder of the population is nucleated in successively larger and fewer towns populated by specialized semiskilled workers and small merchants. Finally, a few cities (Khorat, Udonthani, Khon Kaen, Ubon Ratchathani) have grown as centers of skills, distribution, finance, and entertainment. The progress of these cities and towns, on the whole, would seem to be related to the progress of the individual farmer in the outlying settlements.

Communication by distribution or exchange of printed media is almost nil in most of the rural areas. Without the facilities for easy transfer of capital, commodities, and goods, there is very little of the kinds of marketing and exchange that would facilitate economic specialization, integration of occupations and transactions, and thus new-capital formation.

Several exceptions to complete economic stagnation are noteworthy. Although the Northeast is a net importer of rice in a country that is the greatest-volume exporter in the world, the actual picture is more complicated. A significant effort to produce rice is carried on with varying degrees of success in much of the region. Many secondary exchanges or barters occur in rather modest commodity markets in a number of areas; hence some distribution of local production is achieved and at least some purchasing (bartering) power is created through the willingness to congregate and negotiate in these local marketplaces.

Logging also has been widespread in the Northeast. Sporadic but long continuing, this effort has simply taken timber as available with no attempt at reforestation or other replenishment of depleted reserves. In many areas of the Northeast the only roads are those remaining from logging activity.

Table C1[48] reflects many of the economic and social realities of the Northeast. Although in 1947 the population of the 15 changwads, or provinces, of the Northeast was estimated to be 6,200,000, the 1960 census showed the figure to be 8,991,543, amounting to 34 percent of the total population of Thailand. But careful estimates made recently suggest that in the 4 years ending in 1964 the population had increased to at least 10,000,000. Breakdowns of population per changwad range from 210,000 for Loei, a rather typical province in several ways, to 1,130,000 for Ubon Ratchathani. Population density likewise ranges from 19 persons per square kilometer for Loei to 85 for Roi-Et and 87 for Mahasarakham provinces respectively; for the latter this means that if the population were divided equally, each person would occupy a square of land a little larger than 100 by 100 m. Emphasis is placed on this proportion for, although it certainly does not compare with many areas of the world including many large cities and well-developed agricultural regions, it nonetheless approaches criticality for an undeveloped area lacking much in the way of organization for public health. Although data are not immediately available on the human fertility rate in Northeast Thailand it is a reasonable conjecture that it is fairly high, with only the high mortality resulting from unsafe drinking water and poor sanitation holding the population expansion to its present rate.

With the exception of the interesting variety of natural resources in Loei and the very minor occurrence of gold in Udonthani provinces, the list is meager and monotonous for the remainder of the Khorat Region, including timber, some ornamental woods, and salt lick. In terms of contribution to the direct needs of the people, the soil, although generally poor, is probably the most important natural resource, making possible the crops listed for each province.

The principal crop, wetland rice, which requires very little in the way of organic and mineral nutrients, is much better suited to the soils of Northeast Thailand than may be commonly understood. In addition to the ever-present rice cultivation, other crops such as cotton, sugarcane, jute, coconut, and peanuts thrive in various specific areas. Some corn (maize) is grown and is evidently finding increasing acceptance, but the crop in many places appears stunted and is probably inadequately nourished. Tobacco, pepper, mulberry plants for silkworms, and other minor crops are cultivated carefully and intensively where possible, especially in two specific situations that are, from the standpoint of plant ecology in the Khorat Region, rather unique but, unfortunately, restricted. One of these is the soil around human dwellings where

animals are kept and in some places under the houses that rest on stilts. As a result of both human and animal occupation the soils are relatively rich in nitrogen and phosphorus and are prized accordingly. In some areas it is even a practice to rent a herd of water buffalo to spend their nights in a given place for a month or so, around a house or within a small tract being prepared for special cultivation. The second unique cultivation site, reflecting in a different way the unsuitability of most soils for cultivation, is the termite mound. Occurring almost throughout the Northeast these small heaps or hillocks several feet high are built by termites, which bring very fine calcareous clays to the surface of the ground. Such clays are badly needed in the silty and sandy soils of the region and provide ideal material for cultivation of small but desirable crops.

Occupations in the Northeast are principally farming of all kinds, animal raising, logging, and some skilled manual work such as pottery and earthenware manufacture, handicraft and weaving, and boatbuilding around Nongkai. Some fishing occurs not only in the Mekong but in the many semipermanently flooded areas inland where the fish provide at least some protein for a population lacking it seriously. Fish raising is carried on to some extent and could probably be greatly increased if effort were devoted to adapting species to local conditions and vice versa. Silkworm culture is widespread, centering more or less in Roi-Et and Kalasin provinces, but it is a tedious business. The silkworms need better protection from parasites, greater assured supplies of mulberry, the nurturing of disease-free eggs, and probably new biological strains adapted more completely to local conditions. Improved procedures for reeling and spinning the silk, plus innovations in techniques of dyeing and weaving would probably confer economic benefit on the area by helping to make silkworm culture a more profitable occupation. As it is, much or most of the weaving is for clothing to be worn locally.

The salient factor in the entire distribution of occupations in the Northeast is that farm households make up roughly 87 percent of the total, and hence the inevitable problem of securing an adequate water supply for a population dispersed through thousands of separate villages. Changwad revenues are very low, amounting to something between 1 and 3 baht per person per year. Budgeted expenditures are necessarily on the same order, with the result that very little can be accomplished by the provinces in the direction of civil works and construction. Only the central government in Bangkok possesses the resources to address the problems of development in Northeast Thailand, and until a tax base can be built in the provinces this situation is not likely to change.

Current Threat and Potential Threat

The present turmoil in Southeast Asia resulting from Communist expansion probably is covered well enough by the press to require little additional exposition. South Vietnam and Laos have been the principal subjects of reporting, with relatively less treatment of the increasingly serious situation in Thailand. Understandably the outbreak of open hostilities between Communist and anti-Communist forces in the former countries involving engagements between regular troops on both sides has probably been more newsworthy.

TABLE C1

Selected Demographic and Economic Data of Northeast Thailand[a]

Changwad	Population, 1960 adjusted	Area, km^2	Population density, persons/km^2	Natural resources	Agricultural Population		Principal occupations	Importc
					Percent of total population	Number		
Kalasin	426,795	7,651	56	Timber	93	396,919	Rice farming; animal raising; crop cultivation	Rice, cotton, coc
Khon Kaen	844,075	13,075	63	Timber	85	717,463	Rice farming; crop cultivation; animal raising; earthenware manufacture	Rice, tobacco, su
Chaiyaphum	486,473	10,786	45	Salt lick, timber	91	442,690	Rice furming; fruit growing; crop cultivation; animal raising; logging	Rice, fruit
Nakhon Phanom	436,482	9,744	45	Woods	87	379,739	Rice farming; fruit growing; crop cultivation; tobacco planting	Rice, tobacco, cot
Khorat	1,094,774	19,590	56	Timber	84	919,610	Rice farming; fruit growing; earthenware manufacture; animal raising; weaving	Rice, corn, peanu
Buriram	583,585	10,771	54	Timber	88	513,555	Rice farming; crop cultivation; fruit growing; fishing; weaving	Rice, sugarcane, pepper
Mahasarakham	499,373	5,761	87	Salt lick	92	459,423	Rice farming; crop cultivation; animal raising	Rice, jute, peanut
Roi-Et	668,193	7,854	85	Timber	93	621,419	Silkworm breeding; silk weaving; cotton growing	Cotton, silk, rice
Loei	210,535	10,939	19	Sapphire, teak, iron, manganese, lead, silver, tropical timbers	90	189,482	Rice farming; cotton growing; pepper, corn, peanut, and sesame cultivation; silkworm breeding; weaving	Cotton, corn, pep[aeed
Srisaket	601,356	8,814	68	Timber	94	565,275	Rice farming; cotton growing; sugarcane planting; melon, onion, and garlic cultivation; animal raising; freshwater-fish raising	Watermelon, sugar
Sakhon Nakhon	426,755	9,539	45	Wild products	88	375,544	Rice farming; pepper, cotton, and jute cultivation; animal raising; earthenware manufacture; areca-nut growing	Rice, sugarcane, coconut, betelnu
Surin	581,732	8,784	66	Woods, teak	91	529,376	Rice farming; weaving; pottery; silk weaving; handicraft	Rice, jackfruit, m tobacco, corn
Nongkhai	256,530	7,222	36	Timber	79	202,659	Rice farming; fishing; boatbuilding; earthenware manufacture; tobacco planting	Tobacco, rice, co cane, lamyai, m
Udonthani	744,174	16,607	45	Salt lick, timber, gold	86	639,990	Rice farming; crop cultivation; animal raising; salt-lick production; handicraft	Rice, sugarcane,
Ubon	1,130,712	22,758	50	Woods	88	995,027	Animal raising; logging; rice farming	Tobacco, cotton
Total	8,991,544	170,224	53		88	7,948,171		

[a] 1 baht = $0.05 US (approximately).

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TABLE C1

Selected Demographic and Economic Data of Northeast Thailand[48]

Natural resources	Agricultural Population: Percent of total population	Agricultural Population: Number	Principal occupations	Important crops	Total area in agriculture: Percent of total area	Total area in agriculture: km²	Cropland irrigated: Percent	Cropland irrigated: km²	Number of villages	Changwad revenue, 1963, bahts[a]
r	93	396,919	Rice farming; animal raising; crop cultivation	Rice, cotton, coconut, tabacco, silk	19	1,453	21	305	645	605,908
r	85	717,463	Rice farming; crop cultivation; animal raising; earthenware manufacture	Rice, tobacco, sugarcane, jute	28	3,753	28	1,051	1,363	2,108,190
ck, timber	91	442,690	Rice farming; fruit growing; crop cultivation; animal raising; logging	Rice, fruit	17	1,833	54	990	614	1,686,359
	87	379,739	Rice farming; fruit growing; crop cultivation; tobacco planting	Rice, tobacco, cotton, pepper	11	1,071	25	268	822	395,955
r	84	919,610	Rice farming; fruit growing; earthenware manufacture; animal raising; weaving	Rice, corn, peanuts	26	5,093	29	1,477	1,755	2,152,478
r	88	513,555	Rice farming; crop cultivation; fruit growing; fishing; weaving	Rice, sugarcane, coconut, cotton, jute, pepper	30	3,231	46	1,486	878	932,356
ck	92	459,423	Rice farming; crop cultivation; animal raising	Rice, jute, peanuts, cotton	40	2,304	16	369	961	683,773
r	93	621,419	Silkworm breeding; silk weaving; cotton growing	Cotton, silk, rice	45	3,534	24	848	1,321	1,061,208
re, teak, iron, mang- e, lead, silver, trop- timbers	90	189,482	Rice farming; cotton growing; pepper, corn, peanut, and sesame cultivation; silkworm breeding; weaving	Cotton, corn, pepper, peanuts, sesame seed	4	438	32	140	400	426,239
r	94	565,275	Rice farming; cotton growing; sugarcane planting; melon, onion, and garlic cultivation; animal raising; freshwater-fish raising	Watermelon, sugarcane, onions, garlic	31	2,732	18	492	1,075	652,804
oducts	88	375,544	Rice farming; pepper, cotton, and jute cultivation; animal raising; earthenware manufacture; areca-nut growing	Rice, sugarcane, cotton, pepper, corn, coconut, betelnut	20	1,908	18	343	606	495,983
, teak	91	529,376	Rice farming; weaving; pottery; silk weaving; handicraft	Rice, jackfruit, mangos, sugarcane, tobacco, corn	33	2,899	21	609	1,079	1,594,132
	79	202,659	Rice farming; fishing; boatbuilding; earthenware manufacture; tobacco planting	Tobacco, rice, cotton, peanuts, sugarcane, lamyai, mariah plums	10	722	16	116	444	944,675
k, timber, gold	86	639,990	Rice farming; crop cultivation; animal raising; salt-lick production; handicraft	Rice, sugarcane, pepper, cotton	21	3,487	35	1,220	987	2,391,887
	88	995,027	Animal raising; logging; rice farming	Tobacco, cotton	27	6,145	16	983	2,198	1,535,553
	88	7,948,171			24	40,603	26	10,693	15,148	17,667,500

B

Thailand, however, as a partner in the Southeast Asia Treaty Organization as well as an ally of the US and South Vietnam in the struggle centering in the latter country is fully committed politically to the anti-Communist cause. This commitment is not without wisdom in terms of Thailand's great potential for economic development as well as its long tradition of independence and self-government, but it is also a courageous one in view of its military and political vulnerabilities. Cambodia has been consistently hostile to Thailand, and small shooting engagements have erupted recently in border areas. The Kingdom of Laos is on excellent terms with Thailand but does not control large areas within the country that are dominated by the Communist Pathet Lao in a number of places very close to the Laos-Thai border. Relations with Burma have been friendly enough, but in view of Burma's internal instability these relations could change abruptly. Except for southernmost Thailand's Malaysian border where separate but probably related troubles exist, the most sensitive and vulnerable region of the entire country is Northeast Thailand, which protrudes eastward deeply enough into the center of the Southeast Asian Peninsula to be bordered on three sides by Laos and Cambodia. Within this region, whose poverty and lack of development have been summarized above, lives a target population whose possible and potential subversion represents the main current threat to the Kingdom of Thailand.

This group includes first of all the rather large proportion of non-Thai living in the Northeast. In addition to the very large number of ethnic Lao, a group of at least 40,000 Vietnamese, refugees from North Vietnam during the war with the French, have settled mostly in the border provinces and particularly around Nakhon Phanom. Not unsympathetic to North Vietnam, many of them regard Ho Chi Minh with admiration verging on reverence, and his photograph occupies the place of honor in their homes (Murphy,[49] 1965). Although many of these people have been repatriated to North Vietnam, it has been assumed for some time that many probably find their way back into Thailand after indoctrination in techniques of subversion.

Although Communist activity in the Northeast dates back at least to the late 1920's, propaganda and agitation have become intense much more recently, in the late 1950's, and an increase in various kinds of terrorism has occurred from 1963 through 1965 and 1966. Early in 1965 Marshal Chen Yi, Foreign Minister of Communist China, proclaimed that Thailand was the next target and that a national liberation organization was being readied for an attempt against the RTG. Present indications are that the subversion and the "strategy of protracted conflict," as Communists call it, can become considerably worse in the Northeast before being countered by all the means now employed to that end. For example, the many-faceted effort to develop and improve water supply, sanitation and public health, water distribution, irrigation, and surface-water management in Northeast Thailand will probably better the lives of some millions of people living in the region but will require a period of years for completion.

Meanwhile, however, insurgency is under way in the Northeast aimed at bringing that region under Communist control and, ultimately, assaulting and toppling the RTG. If this insurgency follows the accustomed pattern of the "strategy of protracted conflict" used in "wars of national liberation," it will intensify until it either succeeds or is suppressed at some point in its development by the government through police action or force of arms. Beginning with

an extended period of propaganda, sedition, agitation over distorted or trumped-up issues, and outright subversion, it will proceed along the well-known course of the creation of "shadow" local governments, the levying of tribute and illegal taxes, and terrorism aimed both at removing local opposition and discrediting the power of the police and military forces to protect either themselves or the civil population. It will proceed to overt small-unit guerrilla operations including strikes and ambushes by insurgents who disengage, dispersing if necessary, to return either to innocent occupations or to base camps in less accessible terrain. Finally, as in Laos and South Vietnam, battalion- and regiment-sized tactical operations will be mounted, requiring at least semiconventional maneuver, deployment, and logistics.

As brief as this may be as a projection of actual into potential threat, it nevertheless is not improbable when, as, and if the insurgency intensifies. Should this happen, the RTA would have to consider the problems of deployment.

Because of the specific character of water difficulties in Northeast Thailand, water supply for the RTA could be a complicated problem. Beyond that it could be a significantly dangerous one. The Army could find itself in the predicament of alienating the very people it is trying to help, by appropriating water from their customary sources to satisfy its requirements, possibly generating criticism to the effect that the RTA would thus deprive the people of their water. Justifiable or not the accusation could be more damaging than the fact, and Communist agitators would be quick to exploit such a situation to create ill will based on something the citizens could see before their very eyes.

SCENARIO AND OPERATIONS PROJECTIONS

General

Through successive levels of intensity of insurgency, appropriate military measures and deployments are required. Although no two insurgencies are exactly alike, certain common features seem to characterize the progress of most of them. These are iterated in varying ways but for purposes of this study the definition of levels of intensity of insurgency are those established by the US Army as follows:[6,7]

Phase I, Latent and Incipient Subversion. This phase ranges from circumstances in which subversive activity is only a potential threat, latent or already incipient, to situations in which subversive incidents and activities occur with frequency in an organized pattern. It involves no major outbreak of violence or periods of uncontrollable insurgent activity. This phase, marked by organization, subversive activity, agitation, and propaganda, is a period of preparation for the violent struggle to overthrow the government.

Phase II, Organized Guerrilla Warfare. This phase is reached when the subversive movement, having gained sufficient local or external support, initiates organized guerrilla warfare or related forms of violence against the established authority. Propaganda and other subversive activities are intensified.

Phase III, War of Movement. The situation moves from Phase II to Phase III when insurgency becomes primarily a war of movement between organized forces of the insurgents and those of the established authority. A rival insurgent government may be announced to seek recognition and belligerent status. All previous activities are intensified.

These phases of insurgency, actual and potential, are treated successively in the context of Northeast Thailand in the present and immediately foreseeable future, considered in terms of organization of military and paramilitary forces of the RTG. Force structures, deployments, and water requirements are generated in response to insurgent activity and threat assumed reasonable and plausible at the appropriate levels of intensity. The analysis takes the form shown in Fig. C1.

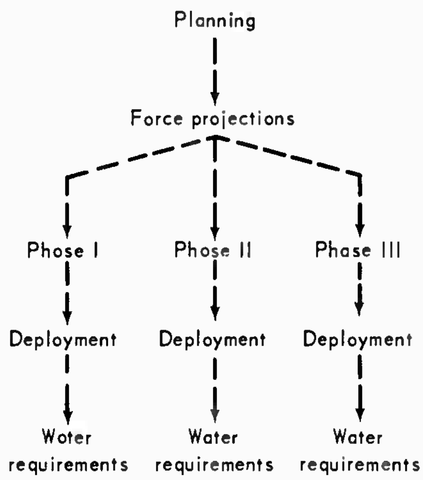

Fig. C1—Diagram of Analysis of Water Requirements in Relation to Force Projections at Various Levels of Insurgency

Scenario-type projections are made at each level of intensity of insurgency, although the situation existing as of late 1966 is not entirely conjectural as to Phase I insurgent activity. For this reason a distinction is made between actuality and additional scenario information, and separate graphics are used to portray Phase I threat. Scenarios are based principally on the terrain of Northeast Thailand; the character of the Thai-Laos and Thai-Cambodian borders; conditions on the other side of these borders; the distribution of cities and towns, roads, and railroads in the Northeast; time-distance relations for operating forces; and the general character of the Communist insurgencies in Laos and South Vietnam with emphasis on the feature of base-camp preparation, which is thought particularly applicable to Northeast Thailand. Information relating to each item on this list is from the open literature with emphasis on news periodicals rather than extended analyses.

No implication is intended that the government of Cambodia is involved with or condones infiltration into Thailand from its territory, but it appears that trained and competent insurgents could utilize the Cambodian-Thai-border area for purposes of their own without the sanction of Cambodian authorities.

Force levels and deployments as well as unit structures and strengths are approximate at best and can be misleading if interpreted for purposes other than those of this study. No specific named or numbered units are considered, nor are the many units that would provide special forms of support whose water requirements are met in large-base water systems or other existing development or construction. Thus it is pointless to construe any particular RTA order of battle from the scenario material. A breakdown of assumed unit strengths is shown in Table C2, which lists strengths of RTA units discussed in the scenario-type force projections for each phase of insurgency. Strengths shown are very approximate and based only on general organization, not on specific TOEs.

TABLE C2

Assumed Unit Strengths of RTA Units

Unit	Assumed strength
Rifle company	200
Rifle company, reinforced	300
Infantry battalion	900
BCT (rs)	1000
BCT	1200
Infantry regiment	3500
RCT (rs)	3800
RCT	4500
Cavalry squadron, pack	1300

Two paramilitary organizations are considered, the PP and the BPP. Although generally operating from fixed-base headquarters, both organizations can and do deploy in quasi-military configurations and under some circumstances would require water for the same purposes as regular troops. No attempt is made to indicate all the separate stations and strengths of the PP or BPP; instead a general relation is assumed overall between army strength and police strength such that total police strength is always half the strength of the total army forces deployed. Thus army strength multiplied by 1.5 equals total military-paramilitary strength in any area and for each level of insurgency. The VDC is not considered in this study because of its fixed-base posture and accustomed local water supply.

Synopsis

Potentially the totality of insurgent effort would include the occupation of caves, tunnels, and other campsites in such easily defended terrain as the forests and rock lands of the Phupan Mountain Range, extending northwestward from Mukdahan, by regular troops of the Pathet Lao infiltrated across the Mekong from Savannakhet or Thakhek in Laos. The same could happen in Loei Province with the insurgents able to go either southeastward past Udonthani into the Phupan Range or more directly southward along the great scarps and forests south of Udonthani, west of Khon Kaen, and toward or north of Chaiyaphum. The same routes of infiltration (and concomitant base building) could

be used to loop southward and then westward around Ubon Ratchathani or southward across Friendship Highway and eastward around Nakhonrajasima, linking if necessary with insurgents from Cambodia in the widely forested and hilly southern margins of the Northeast. From these principal infiltration routes, secondary and tertiary campsites and caches could be built more or less according to a dendritic pattern into the broad, more heavily farmed central areas of the basins on either side of the Phupan Range that constitute Northeast Thailand. From these conjectural invasion arteries, gaining strength and permanence from major bases excavated into the earth in rough hilly ground with approaches protected by heavy forest, vast capillary networks of insurgent logistics and communications could be maintained. The analogy is with the safe-havens areas of South Vietnam where the Viet Minh and Viet Cong have been ensconced for years in major bases that support the assault forces of the National Liberation Front in South Vietnam. In any case, based on the general nature of most insurgencies, the centers of strength will be in forbidding terrain from the standpoint of aggressive counterinsurgent military operations.

Force must be met with force. Whatever police and military counterforce is required to suppress violence, destroy the insurgents, and maintain order must be brought to bear wherever needed. Police organizations, by the nature of their mission, are distributed throughout the country in appropriate strength for normal peace-keeping responsibilities. To meet the intensity and variety of guerrilla strike operations, however, field-maneuver elements of considerable staying power are required, as are the effects of combined arms. Thus the police need reinforcement by regular military units, which must move out of garrison and into the field. Any deployments of the RTA most likely will have to respond to insurgent strike operations in more open, poorly defendable terrain and pursue the strike forces into their more secure "havens" terrain. To do this the RTA will need to establish its own network of bases throughout the provinces, or changwads, and in the secondary jurisdictions, or amphurs. These bases will require all kinds of logistical support, most of it involving equipment and supplies procured elsewhere in the country and transported into the base areas.

An immediate logistical burden is water supply. Because water for military requirements is sought in the field where units are deployed, a probabilistic element is introduced into logistical support procedures. Water must be used and, to be used, found. Either new natural resources must be located and tapped or existing supplies utilized.

Phase I Insurgent Activity: 1959–1966

Hard-core Communists establish themselves in various areas throughout Northeast Thailand for purposes of building cells and recruiting locally from dissident citizens and also to "plant" covert party members in village, tambon, amphur, and changwad governments in order to build into positions of influence and responsibility. Persons with criminal backgrounds or who otherwise fear the police are recruited for either local activity or, if intelligent, training in North Vietnam for further party work in Thailand. Exfiltration of trainees across the Mekong and infiltration of insurgents are accomplished through established procedures in several areas and supervised by insurgent specialists in these techniques. Traffic is expanded to accommodate supplies and

equipment at the most successful infiltration points (Fig. C2) and cadres enter the country along sparsely settled bases that require several years' preparation, particularly for excavation. Other infiltrating teams bring weapons and ammunition for caches at critical points. As recruits are gathered and trained, political-action cells are formed for dissemination of propaganda and political agitation by rumor, slander, and falsehood. The RTG is criticized in any and every way that accords with local problems and needs, real or fancied. Security cells are formed to monitor police activities and operations. Workers are infiltrated and recruited from local cells to assist in excavation and construction of secure bases in hilly forested terrain that is difficult of access. Indignation meetings are called against actions of village authorities, headmen, or police who have taken action against some person or persons and caused grievances. Martyrs are sought, and citizens are incited and exhorted to rise against police. Village leaders attempting to clarify issues or calm troubled situations may be murdered by stealth as enemies of the people.

Agitation grows as more party members are recruited (Fig. C3); police are ambushed, and national and provincial establishments discredited generally. Base construction continues. Clandestine radio broadcasts in the local dialects foment seditious thought and activity and spread unsettling rumors of the total inadequacy of local or national authorities to cope with problems of public safety and welfare. Professional Communist terrorists infiltrate, and Radio Peking announces that it will back a War of National Liberation in answer to the needs of millions of citizens of Northeast Thailand in their just struggle against the imperialist national government. All activity is stepped up, and exchanges of fire occur between infiltration teams and BPP. As bases are constructed and supplied, local Communists are supervised by specialists in reconnaissance and mapping from North Vietnam, and special-purpose maps are prepared of insurgent areas of responsibility in the vicinity of each base. Roads are reconnoitered, traffic is observed, and potential targets are defined and mapped. Preparations begin for establishing shadow tambon governments in areas near insurgent bases. During all this period continuous broadcasts and comment are heard from the Communists stressing the lack of water, roads, and assistance from the RTG; the suffering from disease; the lack of concern for peoples' happiness in drafting youth into the RTA; and the spending of money for materiel that could otherwise be spent on local betterment.

Phase I insurgent effort is completed when real dissatisfaction has led to partial alienation of the general population, when spurious issues are well implanted in the popular mind, and when the construction of the initial array of major bases is completed.

Force Projections. Projections for counterinsurgent forces in Phase I are actual rather than conjectural and can be enumerated in detail, but the Mobile Development Units, civil development agencies, social workers, public health people, etc, are not considered in this study as deployed forces making unforeseen and heavy demands on water supply in local areas.

Effective RTA forces include (Fig. C4) an RCT at Khorat, an RCT at Udonthani, an RCT at Ubon Ratchathani, and a pack cavalry squadron at Khon Kaen, all in garrison. Unit strengths are listed in Table C2. It is assumed that, in Phase I, paramilitary forces such as PP and BPP would operate more or less independently and ordinarily would not rely on RTA support for water supply.

Fig. C2—Phase I Activity—Infiltration
Scenario 1959–1966.

Expectable infiltration routes, based on terrain, of hard-core Communist cadres choosing sites and constructing permanent operating bases, mainly underground

Fig. C3—Phase I Activity—Agitation, Terrarism, Prapaganda[50]

Bosed on onolysis of English-longuage public newspopers in Bangkak ending December 1965.

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Fig. C4—Phase I Deployments of RTA Forces
Scenario 1959–1966.

Boundary of AOR for unit indicated

RCT   Cavalry squadron, pack

Deployment. The AORs shown in Fig. C4 are conjectural and are drawn only in a way to suggest plausible ranges of deployment and consequent distances of lines of communication for logistical purposes. In keeping with conditions in Phase I of insurgency and because of the local availability of police units, the RTA would deploy out of garrison probably one battalion at a time if at all; the necessity for deployment of two battalions to a single place would suggest the onset of Phase II and the need for additional forces, deployments, and AORs in Northeast Thailand.

Each RTA RCT in the area of concern is supported by one engineer company; thus, if battalions are deployed in different directions, the engineer company would have to split into platoons in order to render support. For example, if one battalion of the RCT at Udonthani were moved into the field in the vicinity of Loei, the entire engineer support company could accompany it because the garrison forces would need no special support, but if one battalion moved to Loei and a second battalion moved to the vicinity of Nongkhai, engineer company headquarters would probably stay at Udonthani, with platoons deployed to the other locations some distance apart. Similarly the RCT at Khorat conceivably could be called on to send one battalion to Chaiyaphum and another to Buriram with consequent demands on engineer-support capability. The point is reiterated that under Phase I conditions such multiple deployments are not probable until insurgent activity increases toward the threshold of Phase II; then engineer support might have to be spread very thin and at considerable distances until regional force levels could be increased.

Paramilitary forces (BPP and PP) operate in tactical deployment in Phase I more frequently than the RTA but have no service or support force similar to the RTA engineer units.

Phase II Insurgent Activity: 1967–1970

General unrest, alienation of the population from the national government, and disaffection over lack of progress in civil development are widespread in Northeast Thailand. People in Buriram, Surin, and Srisaket complain that they need roads; people in Sakhon Nakhon and Kalasin say they must have water and the government has not done anything to help them, although they must pay taxes for buildings in Bangkok to house more government; people in Ubon say the noise from jet airplanes scares their pigs and the litters are smaller than before; people in Loei say the government spends all its money to buy American tanks that nobody could possibly need rather than to build a railroad into Loei to carry out the ore they need to sell; people in Udonthani complain that the noise of the jets, like thunder, makes more rain fall from the sky and the floods are worse than in other years; people in Nakhon Phanom and Roi-Et say the police are interfering with the peoples' rightful occupations and pleasures by imposing illegal curfews at night, and that it is well known that they tortured a man from a nearby tambon until he died, and that soon it will be necessary to take public action against the police to make them account to the people for their crimes; people in Khorat say the Americans have forced prices up too high on all the goods for sale in town and are stealing girls to use as slaves, and the national government does nothing to stop them. An elderly man, two women, and two small children are shot to death early one morning in a village west of Mukdahan during an exchange between PP and a terrorist squad; by

nightfall every tambon within a radius of 75 miles has heard that the police have murdered some defenseless citizens, but no one understands how the news traveled so rapidly and accurately. Indignation meetings are called in many amphurs, and a major police post in Mukdahan is wiped out by an attack the same night, marking the beginning of a continuous siege of ambushes along the roads from Ubon to Roi-Et, Ubon to Mukdahan and Nakhon Phanom, and Kalasin to Sakhon Nakhon and Nakhon Phanom. Police and police stations are prime targets and weapons are captured whenever possible. Genuine guerrilla warfare is under way and, in areas where violence is greatest, taxes are levied by representatives of the "Peoples' Free Government of Thailand" (PFGT). Villages not cooperating find decapitated bodies of their phuyaiban (chiefs) in front of their houses. Guerrilla units of 20 to 30 men strike quickly and where least expected and are gone by the time the police can respond. Additional taxes in rice, pigs, chickens, and ducks are demanded "to support the just struggle of the PFGT against the ruthless oppression of the people by police units of the traitorous and reactionary government in Bangkok." Deploying, the RTA forces suffer heavy casualties in road ambushes; soldiers are warned to defect to the "Free" Thai government or be treated as gangsters; numbers of mutilated corpses of RTA troops are found in villages near RTA camps. The capital of the PFGT is proclaimed in Sakhon Nakhon, and continuous proclamations and exhortations against the "bandit" Bangkok government are broadcast from the "capital," but the radio is discovered to be in the mountain 20 km to the southwest.

Starting in 1968 guerrilla strikes occur throughout the Northeast (Fig. C5) and guerrilla forces are estimated first at 1500, but a year later at 5000. The RTA attempts to set up secure villages with defensive perimeters, but the people are sullen and uncooperative. Agent networks do not function well, yielding much false information. The RTA fights with vigor and resolution but receives no help from the civilian population. Cooperative local authorities or private citizens are murdered almost immediately, and gradually the RTA is included with the police as "agents of imperialist aggressor ruling circles of the bandit government." Local recruiting provides logistical support personnel for the Communists, but the attack forces are composed mainly of Pathet Lao. By 1969, infiltration accelerates to about 20 times the 1966 volume of men and materiel, and further development and stocking of the secure bases in the havens areas occurs. By the end of 1970 the counterinsurgent effort by military and paramilitary forces is clearly losing as territory is yielded slowly but steadily to the PFGT. Although the counterinsurgent effort is much better and more efficient in 1970 than in 1967, the Communist insurgents have overcome this improvement by sheer increase in forces infiltrated, all under the guise of a simple straightforward "peoples' revolt" against Bangkok.

Force Projections. Five RTA infantry regiments are considered necessary at the outset of Phase II with the realization that three RCT in garrison are not really in a suitable position to respond to strikes and ambushes rapidly enough to engage the insurgents. With the principal emphasis on rifle platoons and companies and a general lack of opportunity for utilization of weapons larger than rifles, machineguns, and mortars, the former RCT organizations are dissolved, and artillery and tank units are retained in former RCT headquarters areas but placed under division control. However, because of the character of operations and support requirements, combat engineer companies

Fig. C5—Phase II Activity—Logistical Buildup, Small-Unit Actions
Scenario 1967–1970.


Major routes of infiltration of equipment and supplies for logistical support of operating bases


Expectable direction of thrust of insurgent light ambush and strike units, of platoon to company size, against roads, railroads, outposts, police stations, depots, etc

are assigned to regiments, and engineer platoons are reassigned to battalions, so that battalions and regiments are reorganized as combat teams, BCT and RCT, with provision for reattaching tanks and artillery when and if needed. The symbol (rs) for reduced strength is used for these RCT and BCT. Two additional RCT are assigned to Second Army for deployment in the Northeast. According to the unit strengths from Table C1, five RCT (rs) are equivalent to 19,000 RTA regulars. Paramilitary forces would bring the total effective Phase II counterinsurgency force to 28,500.

Deployments. Projections for Phase II counterinsurgent military forces are depicted in Fig. C6, with five principal AORs in the Northeast, each containing an RTA RCT (rs). The northernmost AOR includes the provinces of Loei, Udonthani, and Nongkhai, with a BCT (rs) at the provincial capital of each province and an RCT (rs) headquarters at Udonthani city. Next, an RCT (rs) headquarters and one BCT (rs) at Sakhon Nakhon, a second BCT (rs) at Nakhon Phanom, and a third at Kalasin occupy an AOR comprising those three provinces. Southeast of this a BCT (rs) at RCT (rs) headquarters at Ubon Ratchathani, a BCT (rs) at Srisaket, and a BCT (rs) at Amnat Charoen occupy an AOR comprising the two provinces involved. East of this a BCT (rs) with RCT (rs) headquarters at Roi-Et, a BCT (rs) at Suwan Naphum, and a BCT (rs) at Surin occupy an AOR comprising four provinces: Mahasarakham, Roi-Et, Surin, and Buriram. Finally a BCT (rs) with RCT (rs) headquarters at Nakonrajasima (Khorat), a BCT (rs) at Chaiyaphum, and a BCT (rs) at Khon Kaen occupy the fifth AOR comprising those three respective provinces.

Under the conditions expectable in Phase II, companies would deploy on call from battalion base camps in response to attack, ambush, or other strike alarm but would also undertake patrol activity in company or platoon strength. Such patrols would involve both general reconnaissance and hunter-killer or counterambush techniques. Paramilitary forces would be involved to the utmost and, as a rule of thumb, would add 50 percent to logistical requirements where and when operating with the RTA. Engineer-support-company headquarters would be located with RCT (rs) headquarters in each AOR, but each separate BCT (rs) would require its own engineer support platoon at some distance from company headquarters. This means that each engineer platoon would require full equipment for providing purified water, and in extended operation (meaning more than a few hours) water would either have to be transported to subdeployed units such as companies, or a water-supply squad would have to be codeployed with complete equipment. Under severe pressure in Phase II it is entirely possible that each engineer platoon at BCT (rs) headquarters would be called on to support three companies deployed in three different places and thus would be required to field three separate water-supply squads, each with the necessary equipment. Thus the RCT (rs) would possess capability and equipment in nine separate water-supply squads to support nine companies on extended operations, meaning water production where not obtainable by road transportation between water point and consumers.

Phase III Insurgent Activity: 1970–

As the volume of main-force Pathet Lao, reinforced by Thai and North Vietnamese, builds to progressively greater strengths, and more of the civil population of the Northeast is cowed into cooperation and paying tribute to the

Fig. C6—Phase II Deployments of RTA Forces
Scenario 1967–1970.

Boundary of AOR of headquarters unit

RCT (rs) BCT (rs)

PFGT, the ability of the RTG to cope with the situation begins to deteriorate. Control of much of the rural area has been lost completely. Road convoys, even if heavily armored, have difficulty getting from Saraburi to Khorat, and no convoys have succeeded in reaching Udonthani from Khon Kaen in several months. Udon is a separate enclave and accessible only by air. Mukdahan, Chaiyaphum, and Sakhon Nakhon are completely controlled by the insurgents. Former local governments have been liquidated, their members executed and replaced by Communists. Kalasin is threatened, as are Mahasarakham and Roi-Et. Rapid-response tactical techniques by the RTA have mauled the insurgents badly in several areas. The use of helicopters has been particularly effective after communications procedures were revamped. The insurgents have begun to employ rifle battalions backed up with mortars and recoilless rifles to engage companies sent in by helicopter. Moreover, drawing on experience in Vietnam, the insurgents have devised the "cobra" technique greatly publicized by their psychological operations units. Every tactical unit is claimed to have an exact-strength counterpart lurking nearby where least expected in strike operations, much like the large cobras' often-noted habit of traveling in pairs. In several successive engagements this tactic is employed very successfully against helicopter-borne RTA response forces, resulting in 91 percent casualties in an RTA company the first time employed and 83 percent casualties in the promptly committed relief company. The cobra technique is simply an old-fashioned mousetrap tactic, but the propaganda value is unexpectedly high and it triggers desertions among the RTA. Although the rainy season of the summer of 1970 is particularly bad in terms of losses and morale, intelligence is developed to the effect that the insurgents, now estimated at 15,000 main force plus a much larger number of support irregulars, are in fact mounting their maximum effort and hoping for victory in October. However, their mission-support sites (MSS) in forests well beyond and inside the havens ring of secure bases are detected, and a particularly ambitious regimental attack launched against Khorat from northeastward is crushed by a large force of RTA and PR while preparing to move out, with significant effects on RTA morale.

Through the dry season of 1970–1971 insurgent losses increase as a result of new strike-alarm procedures and even faster response. Exfiltration units, including entire insurgent battalions near Udonthani and Roi-Et, are intercepted and destroyed while attempting to return from MSS to havens bases. Infiltration of replacements and materiel from outside Thailand is slowed greatly and although enough ammunition is on hand for at least 2 years' continued fighting, the insurgents are short of food and are also debilitated by a severe outbreak of anthrax that weakens their 1971 rainy-season campaign. By the dry season of 1971–1972 it is clear (Fig. C7) that the PFGT holds much easily defendable terrain at the periphery of the Northeast in the vicinity of its secure havens bases but cannot grab the interior, particularly in the southern part, because it cannot take the cities of Khorat, Khon Kaen (which was earlier almost written off), Mahasarakham, Roi-Et, and Ubon Ratchathani. Kalasin, although pressured and suffering much violence and terrorism, and Udonthani, although surrounded, display an unexpected civilian antipathy toward the PFGT, and rioters lynch suspected Communists, unknowingly killing the Coordinator of Peoples' Information of the PFGT, the chief of all Communist intelligence

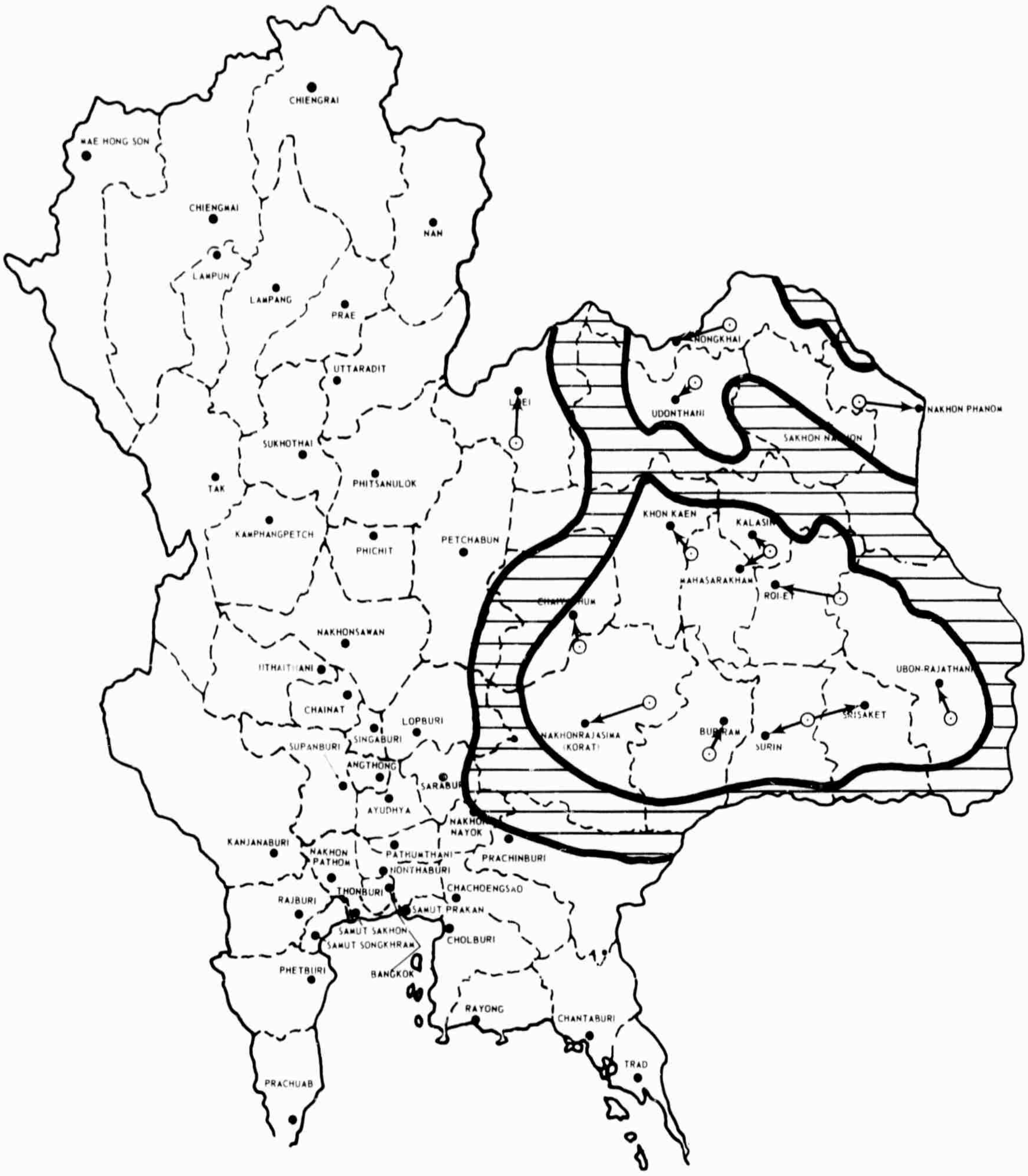

Fig. C7—Phase III Activity—Maneuver and Strike by Large Units; Formation of National Liberation Government
Scenario 1970–

Insurgent havens areas of relatively secure permanent bases, supply depots, and logistical transfer points

Insurgent mission-support site in large-forest terrain for staging and mounting battalion and regimental actions

Insurgent attack against primary target

in the Northeast. During the ensuing reshuffling of the Communist insurgent hierarchy a split develops in leadership, one group adhering to standard Mao doctrine of the protracted struggle and the other calling for an armed Chinese invasion to "liberate" Thailand. Although the RTA is holding its own through the rainy season of 1972 and the insurgent position has deteriorated somewhat, the outcome is far from clear.

And so the conflict continues, but the scenario to this point is sufficient to illustrate the problems involved in operations and water-requirements projections.

Force Projections. Because of the greater numbers of insurgents and the appearance of automatic and heavy weapons with considerable multiplication of firepower, the full-strength RCT force configuration is again used in the RTA Second Army Area in Phase III of insurgency. Additionally, full-strength BCTs as well as reinforced rifle companies are employed to bring maximum firepower to bear. A total of eight RTA RCTs are assigned to the area, representing 36,000 regular troops and sufficient paramilitary forces to bring the total to a 54,000-man counterinsurgent force altogether. Immediately following initial deployment, plans are undertaken for the organization and deployment of 4 additional RCTs to bring the total in the Northeast to 12.

Deployment. Projections for Phase III counterinsurgent forces are depicted as deployed in Fig. C8, with eight areas of responsibility in the Northeast, each including one RCT. The smallest AOR, Loei Province, possesses some of the most difficult terrain. RCT headquarters plus one BCT is at the capital. The second BCT is at Chiengkarn near the Mekong River, and the third is to the south at Wangsa Pung. Next an AOR including Udonthani, Nongkhai, and part of Sakhon Nakhon provinces has RCT headquarters plus one BCT at Udon, a BCT at Nongkhai, and a BCT in the east at Saweng Daen Din. To the southeast the next AOR includes the other half of Sakhon Nakhon Province and all Nakhon Phanom Province, with RCT headquarters plus one BCT at the town of Nakhon Phanom, a BCT at the town of Sakhon Nakhon, and a BCT at Mukdahan. Farther to the south, Ubon Province constitutes an AOR in itself with RCT headquarters plus one BCT at the capital, a BCT at Amnat Charoen, and a BCT at Det Udom. These four AORs complete the Thai-Laotian frontier.

Most of the Cambodian frontier is included in one AOR, comprising Surin, Buriram, and Srisaket provinces respectively, with the RCT headquarters plus one BCT at the town of Surin, a BCT at the town of Buriram, and a BCT at the town of Srisaket.

Three interior AORs remain. In the center of the Northeast is an AOR comprising Roi-Et, Kalasin, Mahasarakham, and a small projection of Buriram. BCT are stationed at the capital towns of the three whole provinces in the AOR with RCT headquarters at Roi-Et. To the west is an AOR comprising Khon Kaen and Chaiyaphum provinces, with RCT headquarters plus one BCT at Khon Kaen, a BCT at the town of Chaiyaphum, and a BCT at Chumpae. Finally, the province of Nakhonrajasima constitutes one AOR, with RCT headquarters and one BCT at the capital, one BCT at Phi Mai, and one BCT at Pakthongchai.

Much or all of the comment on Phase II deployment is applicable to this discussion of Phase III deployment, but with at least two major differences: First, the company and platoon-sized unit deployments of Phase II become BCT and RCT deployments in Phase III, with two-battalion operations perhaps more

Fig. C8—Phase III Deployments of RTA Forces
Scenorio 1970–

Boundary of AOR of headquarters unit

RCT BCT

common than full-regimental operations. Second, AOR are considerably smaller than in Phase II, and forces are increased in each AOR from RCT (rs) to RCTs. Thus larger units are involved but move through somewhat shorter distances. Paramilitary forces tend to retain more or less the same-sized unit deployments of Phase II, contributing platoons and companies to support the dominantly larger RTA units. In terms of a deteriorating RTA ability to cope with increasing numbers of insurgent main-force units, the next step in the Northeast would be the deployment of as many as 12 RCT with correspondingly smaller AOR, but the 8-RCT deployment illustrates Phase III water-supply problems so far as engineer capability is concerned, requiring greater transport distances between support units and consumers. As additional units are committed beyond those indicated in Fig. C8, total water demand increases but not to the point of taxing the available supply (see main body of this document). It might be added, for example, that 12-RCT deployment would decrease requisite areas of water reconnaissance per engineer company and also decrease water-transport distances, although troops and likewise engineer water units might be more active than in a situation requiring only an 8-RCT deployment.

By and large, engineer support would be furnished by platoons responsible to battalions, and less deployment of infantry units smaller than battalion size would afford less fragmentation of engineer-support units into squads. However, these larger units would incur larger and more continuous water requirements than is characteristic of Phase II.

GLOSSARY

aquiclude. A formation that although porous and capable of absorbing water slowly will not transmit it fast enough to furnish an appreciable supply for a well or spring.

aquifer. A rock or soil formation, group of formations, or part of a formation that is water bearing.

aquifuge. A rock that contains no interconnected openings or interstices and therefore neither absorbs nor transmits water.

aquitard. A formation of a rather impervious and semiconfining nature that transmits water at a very slow rate compared to aquifers. Over a large area of contact it may permit passage of large amounts of water between adjacent aquifers that it separates.

artesian basin. A geologic structural feature or combination of such features in which artesian water is confined.

artificial recharge. The increasing and/or raising of the ground-water table by deliberate addition of surface waters to it; includes spreading methods such as basins, furrows, and flooded areas or injecting methods such as vertical shafts, horizontal collector wells, pits, and trenches.

artesian water. Ground water that is under sufficient pressure to rise above the level at which it is encountered by a well but not necessarily under sufficient pressure to rise to or above the surface of the ground.

artesian well. One in which the water level rises above the top of the aquifer, whether or not the water flows at the land surface.

climate. The sum total of the meteorological elements that characterize the average and extreme condition of the atmosphere over a long period of time at any one place or region of the earth's surface.

drainage basin. A part of the surface of the lithosphere that is occupied by a drainage system or contributes surface water to such a system.

ephemeral stream. One that flows only in direct response to precipitation and whose stream channel is at all times above the water table. The term may be arbitrarily restricted to streams or reaches of streams that do not flow continuously during a period of as much as 1 month.

evaporation. The process by which water is changed from the liquid or the solid state into the gaseous state through the transfer of heat energy.

evaporation, total. The sum of water lost from a given land area during any specific time by transpiration from vegetation and building of plant tissue; by evaporation from water surfaces, moist soil, and snow; and by interception. It has been variously termed "evaporation," "evaporation from land areas," "evapotranspiration," "total loss," "water losses," and "fly off."

evapotranspiration. Water withdrawn from soil by evaporation and plant transpiration.

evapotranspiration, actual. The amount of moisture actually disappearing directly into the atmsophere from evaporation and plant transpiration.

evapotranspiration, potential. Water loss that will occur if at no time there is a deficiency of water in the soil for the use of vegetation.

flocculation. Coagulation and rapid precipitation of finely divided solids that normally remain in suspension in water and other liquids.

flood plain. Any plain that borders a stream and is covered by its waters in time of flood.

fluctuation of climate. The differences between the means of 30-year periods.

gaging station. Point at which records of daily fluctuations of the water stage are made for determining the daily flow.

ground water. That part of subsurface water that is in the zone of saturation; the water in the zone of saturation in the sense that it is the basal or bottom water (see also "perched ground water").

ground-water discharge. Discharge of water from the zone of saturation.

ground-water flow. That portion of the discharge of a stream that is derived from ground water.

ground-water reservoir. Commonly used to designate the water-bearing material from which man can extract water.

hydrology. The science encompassing the behavior of water as it occurs in the atmosphere, on the surface of the ground, and underground.

hydrologic cycle. A convenient term to denote the circulation of water from the sea through the atmosphere to the land; and thence, with numerous delays, back to the sea by overland and subterranean routes and in part by way of the atmosphere.

infiltration. The flow of a fluid into a substance through pores or small openings. It connotes flow into a substance in contradistinction to the word "percolation," which connotes flow through a porous substance.

impermeable—impervious. Having a texture that does not permit water to move through it perceptibly under the head differences ordinarily found in subsurface water.

irrigation. The controlled application of water to arable lands to supply water needs not satisfied by rainfall.

leaching. The process of removal of soluble material by passage of water through soil.

perched ground water. Ground water separated from an underlying body of ground water by unsaturated rock or soil. Its water table is a perched water table.

piezometric surface. (a) An imaginary surface that everywhere coincides with the static level of the water in the aquifer. (b) The surface to which the water from a given aquifer will rise under its full head.

percolation. The movement of water under hydraulic gradients through the interstices of a rock or soil, except the movement through large openings such as caves.

permeable—pervious. Having a texture that permits water to move through it perceptibly under the head differences ordinarily found in subsurface water. Permeable rock has communicating interstices of capillary or supercapillary size.

phreatophyte. A plant that habitually obtains its water supply from the zone of saturation either directly or through the capillary fringe.

pond. As constructed by the Royal Irrigation Department—a rectangular sloping excavation generally about 80 m on a side with a smaller rectangle 40 m square in the center, filled by rain and ground waters only; also any excavation, natural or dug, that is primarily fed by rain water and/or ground water. May locally be the result of the dissolving of underlying evaporite deposits.

porosity. The ratio of the aggregate volume of interstices in a rock or soil to its total volume. It is usually stated as a percentage; a measure of the water-bearing capacity of the material.

potable. A term applied to water suitable for human consumption. More or less synonymous with "pure" water or good-quality water in which chemical and biological contaminants are at levels acceptable by health standards; may be used locally to describe water acceptable to human taste.

precipitation. The total measurable supply of water received directly from clouds as rain, snow, and hail; usually expressed as depth per day, month, or year.

rainfall. The quantity of water that falls as rain only; not synonymous with precipitation.

rainfall-runoff deficit. The total loss of water through evaporation, transpiration, and deep infiltration expressed in absolute terms.

recharge (of ground water). Intake; the processes by which water is absorbed and is added to the zone of saturation; also used to designate the quantity of water that is added to the zone of saturation.

runoff. The discharge of water through surface streams. This term has a double use, like precipitation, being applied also to the quantity of water that thus runs off. The runoff of a drainage basin is the water that is discharged from the basin as surface water.

safe yield (sustained yield). The rate at which water can be withdrawn from an aquifer for human use without depleting the supply to such an extent that withdrawal at this rate is no longer economically feasible. The amount of water that can be withdrawn from a ground-water basin annually without producing an undesired result.

sediment. Fragmental material transported by, suspended in, or deposited by water or air or accumulated in beds by other natural agents.

seepage. The downward movement of gravity water toward the water table.

soil moisture recharge. The difference between precipitation and evapotranspiration when precipitation exceeds evapotranspiration and soils are not at field capacity.

specific capacity (of a well). The discharge expressed as rate of yield per unit of drawdown, generally gallons per minute per foot of drawdown.

specific yield. The quantity of water that a formation will yield under the pull of gravity if it is first saturated and then allowed to drain; the ratio expressed in percentage of the volume of this water to the total volume of the formation that is drained.

surface runoff. That portion of the runoff that travels over the soil surface to the nearest stream channel.

surface water. Water that rests on or flows over the surface of the land.

tank. In Northeast Thailand, a small reservoir constructed by the building of a low, generally earthen, dam across a drainage way. Maximum heights of the dams through 1965 were about 15 m; most were between 4 and 9 m.

transpiration. The quantity of water absorbed by the crop and transpired and used directly in the building of plant tissue in a specific time. This does not include soil evaporation.

water deficit. The difference between potential evapotranspiration and actual evapotranspiration.

water table. The upper surface of a zone of saturation except where that surface is formed by an impermeable body.

water surplus. The difference between precipitation and potential evapotranspiration when soils are at field capacity.

zone of aeration. The zone in which the interstices of the functional permeable rocks are not filled (except temporarily) with water. The water is under pressure less than atmospheric.

zone of saturation. The zone in which the functional permeable rocks are saturated with water under pressure equal to or greater than atmospheric.

ANNOTATED BIBLIOGRAPHY

CITED REFERENCES

1. Lee W. Huff, "Observations on National Security Organization Mobile Development Unit 2 Operations," Joint Thai-US Combat Development and Test Center, Thailand, Jun 63. CONFIDENTIAL
2. R. L. Pendleton, Thailand, Duell, Sloan & Pearce, Inc., New York, 1963.

   Excellent general geography of Thailand treating the Northeast (the Khorat) separately in many of the subjects covered. Written by the soils scientist responsible for most of the early soils work in the country.

3. "Bangkok World Annual Review, 1965."
4. "Cheap Solar Still Developed," Bangkok Post (Dec 65).

   Describes a cheap solar water still developed by the Mechanical Engineering Division of the Australian Commonwealth Scientific and Industrial Research Organization, ready for commercial production. Initial tests of prototype averaged 344 gal of water per day at a cost of $4 per 1000 gal. The still consists of 10 shallow glass-rooted troughs, each 130 ft long, over a shallow slightly sloping trench lined with polythane. Brackish or salt water is fed down the trough at a slow rate.

5. R. D. Jackson and C. H. M. VanBavel, "Solar Distillation of Water from Soil and Plant Materials: A Simple Desert Survival Technique," Science, 149:(17 Sep 65).

   A description of a simple solar survival still that can be used over bare or vegetated desert soils, or soils with brackish, saline, or polluted water, to produce potable water supplies. Equipment needs are a sheet of clear plastic about 2 by 2 m and a container to collect water. Yields of water in ml per day ranged from over 100 ml on bare desert sand in the worst possible topographic position to over 1900 ml where cut desert plants were added. Finer-grained soils increased the productivity.

6. Dept of Army, "US Army Counterinsurgency Forces," FM 31-22, 12 Nov 63.
7. ——, Special Warfare School, "Counterinsurgency Planning Guide," ST 31-176, May 64.
8. ——, "Field Water Supply," TM 5-700, 11 Oct 65.
9. Daniel, Mann, Johnson, and Mendenhall, International, "Ground Water Exploration of the Khorat Plateau," final report, Bangkok, Jul 61.

   The results of the first large drilling program to develop ground-water supplies in Northeast Thailand. Covers the period June 1958–May 1961. Includes statistics for over 400 wells drilled and a geology map at a scale of about 1:600,000. Currently valuable as the only semipublished record of results of a significant number of drill holes. Will be superseded by the forthcoming Ground Water Bulletin 2 (see Haworth et al, Ref 23).

10. P. E. LaMoreaux et al., "Reconnaissance of the Geology and Ground Water of the Khorat Plateau, Thailand," US Geological Survey Water Supply Paper 1429, 1958.

An early published study on ground-water potential in the Northeast, widely quoted because of its availability. Out of date in many respects, because only four wells had been drilled in the Northeast at the time of the work, but basic thought and theory are still applicable. Many of the recommendations therein have been or are being accomplished.

11. D. B. Doan, "Geological Study of Northeast Thailand," memorandum proposal to USOM, through Advanced Research Projects Agency, 17 Sep 63.

A proposal for detailed geologic mapping of all the Northeast, with priority areas based on the insurgency threat, to provide a sound basis for hydrologic and soils work. Recommends new air photography be flown at 1:20,000 for this purpose.

12. F. R. Moorman, S. Montrakun, and Panichapong, "Soils of Northeast Thailand," Land Development Department, Ministry of National Development, 1964.

An explanation of new classification schemes for soils in the Northeast now in use by the Soil Survey Division. Includes relations to older soil classifications and landforms, and in so doing describes and classifies the extensive alluvial terrace formations. A paper basic to the understanding of the soils of the Northeast.

13. Royal Thai Survey Dept, published maps, 1964.
14. M. L. X. Kambhu, "Water Resources Development in Thailand and Its Policy," Royal Irrigation Department, paper delivered at Economic Commission for Asia and the Far East, 6th Regional Conference on Water Resources Development, Bangkok, Dec 63.

A summary of surface-water works existing and planned in all Thailand, by region, including the Northeast. Plans call for 1000 small reservoirs (tanks) and 16 to 20 medium-sized reservoirs with provision for diversion-irrigation works in the Northeast.

15. US Dept of Interior, Bureau of Reclamation, "Survey of Water Resources, Mun and Chi River Basins, Northeastern Thailand," Mar 65.

Reconnaissance report prepared for AID, US Dept of State, and Royal Irrigation Department, Thailand. An extensively documented report on the irrigation potential, status, and problems in three-quarters of the Northeast. Includes a water-supply appendix.

16. Asni Molagool, "An Investigation of the Water Balance in Northeastern Thailand," master's thesis, SEATO Graduate School of Engineering, Bangkok, 1962.

This is apparently the only available water-balance study prepared specifically for the Northeast. It examines the geographic and seasonal variation of runoff, the areal runoff coefficients, methods used in determining reservoir losses, and infiltration rates and recommends lines of needed further work. Includes generalized maps of mean annual rainfall, runoff coefficients, and soil-moisture deficits. Well done, although basic input data were necessarily weak.

17. Lawrence Sternstein. The Rainfall of Thailand, Indiana University Foundation Research Division, Bloomington, Ind., Aug 62.

A description and analysis of rainfall characteristics in Thailand. Concerned with the annual, monthly, daily, and hourly rainfall patterns as well as the intensity, duration, spacing, and variation of the precipitation. Rainfall regions are identified. All known rainfall data are summarized and evaluated through 1960.

18. L. E. Myers, "Evaporation Retardants: Application by Means of a Water Soluble Matrix," Science, 148: (2 Apr 65).

Description of some of the problems in using monomolecular long-chain-alkanol films as evaporation retardants on water bodies. Recommends a method of application by mixing with a matrix material that dissolves in water as being particularly suitable and economical for small reservoirs and ponds.

19. V. K. LaMer and T. H. Healy, "Evaporation of Water: Its Retardation by Monolayers," Science, 148: (2 Apr 65).

A summary of the principles and status of the application of monolayer films for controlling evaporation losses. Recognizes wind as the environmental variable with the greatest adverse effect on evaporation control. Recommends air application as the most promising method for large reservoirs and gives tabular data on tests.

20. S. N. Davis and R. J. DeWiest, Hydrogeology, John Wiley & Sons, Inc., New York, 1966, p 265.
21. O. E. Meinzer, "The Occurrence of Ground Water in the United States," US Geological Survey Water Supply Paper 489, Dept of Interior, 1923, Fig. 55, p 175.
22. US Geological Survey, Geologic Names Committee, unpublished data, 1954.
23. H. F. Haworth, P. Na Chiangmai, and Charoen Phiancharoen, "Ground Water Resources Development of Northeast Thailand," Ground Water Bulletin 2, Thailand Dept of Mineral Resources, 1967.

A major reference. The stated purpose, ". . .present the basic data collected . . . , to describe the ground water resources . . . and delineate the areas where ground water of satisfactory quality should be available from drilled wells. . . .(is). . .useful for future studies and for those agencies and communities in need of additional water, particularly for domestic purposes and . . . guide. . .for program for drilling 500 or more wells per year."

This report covers the history and present status of geological and ground-water investigations and describes use and applications of geophysical methods, aquifer tests, quality recommendations, and surface-water resources.

Much basic tabular data is included as appendixes, and the report is extensively illustrated, including maps of geology, ground-water availability, depth to water, depth to fresh water, and isopachs of chlorides, hardness, total dissolved solids, and locations of drilled wells.

Users of the maps should recognize that many of the isopachous boundaries are dependent on drill-hole data and as such are dynamic in character and may have changed considerably in detail since 1964.

The geological input is admittedly largely derived from compilations of earlier reconnaissance work and from well-hole logging both visual and geophysical. A shortcoming of the report, although admittedly outside its primary interests in drilled wells, is the cursory treatment and write-off of shallow ground-water resources—those reachable by dug wells.

24. Suwit Watthanachan, "The Origin of Saline Deposits in the Khorat Plateau, Thailand," unpublished master's thesis, University of Alabama, 1964.

A review of the geology and origins of the salt deposits of Northeast Thailand. Includes a geologic map and an isopach map of the top of the first salt beds located in drill holes. Well statistics on 36 holes contacting rock salt are included. Assigns Triassic age to the Khorat series up to the salt-bearing beds, which are identified as Jurassic or younger.

25. Wallace Lee, "Reconnaissance Geologic Report of the Khorat Region," manuscript report in files of Thai Geological Survey and Irrigation departments, 1923.

First geologic study of any consequence in Northeast Thailand establishing the guidelines for later work.

26. G. F. Brown, S. Buraucs, J. Charaljavanaphet, N. Jalichandra, W. D. Johnson, V. Spesthaputra, and G. C. Taylor, "Geologic Reconnaissance of the Mineral Deposits of Thailand," US Geological Survey Bulletin 984, 1951.

The only published study with a geologic map of all Thailand. Map reproduced by Royal Thai Survey Department. Shows some areas of alluvium not shown on later maps of Northeast Thailand.

27. H. F. Haworth, "Exploration for Ground Water, Northeastern Thailand," mimeographed report, Public Works and Engineering Division, USOM, Thailand, 11 Sep 62.

This unpublished report with geologic and ground-water-availability maps at 1:2,500,000 essentially summarizes the data to be published in Ground Water Bulletin 2, of which Haworth is senior author. There are additional details and new information and maps in the bulletin based on another year's drilling, but the basic conclusions are the same.

28. US Army, Pacific Command, "Water Resources," area intelligence reports prepared for US Corps of Engineers by Military Geology Branch, US Geological Survey, circa 1960–61. CONFIDENTIAL

Ozaphane overlays to 1:250,000 Army Map Service (AMS) topographic maps of all Northeast Thailand, with accompanying descriptive tabular data. Table classifies the water resources, both surface and ground water, by symbol and map unit. Surface water is treated in terms of quantity and quality for high- and low-water periods on gpd ratings. Identifies streams, lakes, and marshes as intermittent or perennial. Ground-water potential delimited on basis of geologic units. For each unit the depth-to-aquifers, well-siting, and development problems for both drilled wells (more than 20 ft deep) and dug wells (less than 20 ft deep) and quantity expectations are given.

Probable chemical- and biological-quality limitations are also provided for each unit, as are possibilities for spring locations.

Although these maps represent the largest-scale water-resources maps currently available, their security classification limits their use. A similar treatment by Johnson updates this work to 1963 and is unclassified.

29. C. G. Johnson, "Water Resources at the Khorat Plateau, Thailand," unpublished manuscript and map prepared by Military Geology Branch, US Geological Survey, Dept of Interior, for Chief, Mapping and Geodesy Division, G2, HQ, US Army, Pacific, Jun 64.

This unclassified manuscript report consists of a 5-page (typewritten) text, map coverage of Northeast Thailand at a scale of 1:250,000 (17 sheets), and associated tables. The proposed legend is a tabular treatment of 10 ground-water units that are based primarily on geologic units. For each unit the following are described: (a) the aquifer conditions; (b) the quantity of water expectable with well-production data and specific capacities; (c) quality; (d) springs; and (e) siting and development problems both for wells deeper than 20 ft and for shallower wells. Potential surface-water supplies are outlined by a short paragraph and by symbols showing salty perennial streams and ponds. Other symbols define areas where salty well water may be expectable and the locations and results of drilled wells. Details on all the wells are included.

The work supersedes the PACOM water-resources work in this area and contains more data on the basis of the drilled-well results (to about 1963).

30. Sarot Montrakun, "Agriculture and Soils at Thailand," Technical Division, Department of Rice, Ministry of Agriculture, Bangkok, 1964.

A compilation that includes the data from most of the early soils studies in Thailand, primarily the work of Pendleton and his associates. Includes the analyses of soils samples collected in the period 1935–1941 and the field observations and sections made in the Northeast, together with observations and relations of soils to natural vegetation and agricultural practices. Photography referred to is not included, for all negatives had been sent to Johns Hopkins University for WWII security reasons. Soil terminology is not currently being used by the agency having responsibility for soils mapping in Thailand.

31. S. Rojanasoonthon, "Interim Reports on the Great Soil Group Survey, I: Khon Kaen Study Area," Report SSR 28-1964, Soil Survey Division, Ministry of National Development, Bangkok, Oct 64.

Representative of special studies being done by Soil Survey Division. Contains a soils map of parts of Khon Kaen Changwad at 1:250,000 that is representative of type and detail to be used in Soil Survey Division mapping on a changwad basis.

32. R. Dudal and F. R. Moormann, "Major Soils of Southeast Asia," J. Trop. Geograph., 18: 54–80 (Aug 64).

A classification of soils at the great-soil-group level based on the soil-classification systems of the USDA. Discusses the morphological, chemical, and physiochemical characteristics; distribution and environmental conditions; and land-use potential.

This is the system used in the 1961 Vietnam soil map prepared by Moormann and will be used in the new generalized soil map for Northeast Thailand. The units used equate fairly well to those used by the World Soil Map Group, Soil Conservation Service, USDA.

33. SOGREAH, Agropedological Study of the Upper Nam Chi Basin, Société Grenobloise d'Études et d'Applications Hydrauliques, Grenoble, France, 1960.

Uses the genetic soils groups as developed during French work in Africa and is useful only for some purposes. Very difficult to equate these units to those used in other Northeast maps.

34. R. J. M. DeWiest, Geohydrology, John Wiley & Sons, Inc., New York, 1965.

Excellent basic reference text on the hydrology of ground water, with 115 pages devoted to elements of surface hydrology.

35. M. L. X. Kambhu, Royal Irrigation Department, Ministry of Agriculture, memorandum on water condition, water requirement, and water control projects in the northeast region of Thailand, revision, 1961.

Excellent summary of the history and development of surface-water irrigation projects through 1960. Defines and defends the tank-construction program in terms of water utilization and economic feasibility.

36. Orson W. Israelsen and John B. Smith, "Irrigation and Drainage Practices, Progress, and Problems in the Philippines, Thailand, and West Pakistan," SEATO Graduate School of Engineering, Bangkok, 1965.

A 278-page publication summarizes the problems and solutions, questions, discussions, and comments of 60 engineers with respect to irrigation and drainage in Southeast Asia; 74 pages deal with Thailand and cover history and development of water resources and irrigation practices in relation to agriculture.

37. J. F. Long, M. F. Long, K. Adulavidheya, and S. Pongsuwan, "Economic and Social Conditions among Farmers in Changwad Khonkaen," Faculty of Economics and Co-operative Science, Kasetsart University, Bangkok, Sep 63.

Designated as having average production and income figures for the Northeast, this changwad was studied for the National Economic Development Board to provide a bench mark by which to compare future work and programs. Study was largely by questionnaire covering all aspects of the people's social and economic conditions.

38. Ministry of National Development, National Energy Authority, 1962 Hydrologic Data, Pracendia Press, Bangkok, 1963.

Statistical data for CY62 for the 36 hydrologic stations operated by the National Energy Authority in all Thailand. Also includes data from 31 meteorological stations, 18 evaporation stations, and 6 wind-movement stations. Records not complete for all stations.

39. ____, Royal Irrigation Department, "Water Resources Development in Thailand Completed to the End of 1963 and under Construction in 1964," tables, Bangkok, Aug 64.

Statistics of various types of irrigation projects for all Thailand and maps of their locations at 1:2,500,000. Useful as a source of data for capacities of individual tanks, although specific locations are given only by province and town.

40. O. E. Meinzer, "Outline of Ground-Water Hydrology," US Geological Survey Water Supply Paper 494, Dept of Interior, 1923, p 23.

41. Rafique A. Khan, "A Report on Health Conditions in Northeast Thailand," with particular reference to the province of Ubon, Thai-SEATO Regional Community Development Technical Assistance Center, Ubon, Thailand Bangkok, Jul 63.

Reports primarily on Ubon as the second most populous changwad on the assumption that its health conditions are typical of those in the Northeast; discusses the water resources in terms of human domestic use with reference to the development of sanitary water supplies.

42. W. A. McQuary, "The Development of Community Potable Water Supply Program in North and Northeast Thailand," attachment to memo from E. O'Rourke to T. S. Park, draft report, 29 Jul 65.

A brief background on water-supply availability in Northeast Thailand and the functions and responsibilities of the Thai departments that are concerned with water-supply development. The report also estimates the personnel, commodity, and budget requirements for the proposed water program over the next 3 years.

43. R. Terman, Military Geology Branch, US Geological Survey, unpublished memorandums, 1956.

44. California Resource Board, "Water Quality Criteria," State Water Pollution Control Board Publication 3, 1952.

45. Ath Visuthyothapibarl, Thai Dept of Local Administration, to Commander, Military Research and Development Center, Bangkok, Ltr, 26 Jul 66.

46. D. J. Blakeslee, L. W. Huff, and R. W. Kickert, "Village Security Pilot Study, Northeast Thailand," Report 65-016, Joint Thai-US Military Research and Development Center, Bangkok, May 65. UNCLASSIFIED

A study to develop a data base of information relative to village security. Forty villages in two test areas west of Udonthani were examined.

Considers water supply in relation to seasonal potability (as defined by village users) and location inside village perimeters. For wells inside village perimeters 50 percent were potable, and 80 percent of wells outside were potable; 35 percent

of total wells examined were outside village security perimeters. All but one well was hand dug; water from the one drilled well was not acceptable owing to its odor and salty taste. Community reservoirs, ponds, and streams were outside the perimeters and most were unpotable, of short life, or dried up in dry season.

47. J. Kobayashi, "Chemical Investigation on River Waters of Southeastern Asiatic Countries," Report I, "The Quality of Waters of Thailand," Berichte des Ohara Instituts für Landwirtschäftliche Biologie, 1959, Bd XI, Heft 2, pp 167–233.

    The only known published study of analyses of the river waters of Thailand. Compares the chemical analyses of various sectors of Thailand, also compares them seasonally, and compares them with Japanese rivers.

48. US Operations Mission, Public Administration Division, in cooperation with National Statistical Office, Office of the Prime Minister, and Department of Local Administration, Ministry of Interior, RTG, "Changwat-Amphoe Statistical Directory," Nov 65.
49. C. J. V. Murphy, "Thailand's Fight to the Finish," Fortune, 72 (4): 122 (1965).
50. R. William Rae, "The Insurgency Syndrome," Research Analysis Corporation, Field Office Thailand, unpublished data, Jan 66.

ADDITIONAL REFERENCES

Bunting, B. T., The Geography of Soil, Aldine Publishing Company, Chicago, 1965.

A practical and comprehensive treatment of the geographical concepts of the formation, distribution, and morphology of the Great Soil Groups. Written within the framework of the modern international-regional basis.

Christensen, Knud, A. Nalampoon, and S. Sukhawong, "Vegetation and Soil Analysis of AMPIRT Forest Test Site Pak Thong Chai," Report 65-013, Joint Thai-US Military Research and Development Center, Feb 65.

This study of four 10- by 40-m plots in dry or semievergreen forest was prepared for the ARPA AMPIRT program. The location, height, diameter, and species of trees larger than 5 cm in diameter were collected, together with data on the undergrowth. Vertical and horizontal observation and foot-movement evaluations are given.

Haworth, H. F., "Exploration for Ground Water, Northeastern Thailand," unpublished report, Public Works and Engineering Division, USOM, Aug 62.

Excellent summary data resulting from the exploration programs for ground water through June 1962; ground-water-availability and geology maps at a scale of 1:250,000.

_____, C. Javanaphet, and P. N. Chiangmai, "Report on Ground Water Exploration and Development of the Khorat Plateau Region," Ground Water Bulletin 1, Royal Dept of Mines, Thailand, 1959.

First report by Royal Thai Dept of Mines on the results of initial drilling programs for ground water. Contains partial analyses of 50 wells. Indicates that most wells were near the few motorable roads and that no large-scale drilling program can be developed until more extensive geological and hydrological information is available.

Huff, Lee W., "Mobile Development Unit Follow-Up," Report 64-012, Joint Thai-US Military Research and Development Center, Supreme Command Headquarters, Ministry of Defense, Bangkok, Nov 64. UNCLASSIFIED

This report considers the lack of village water in the Northeast (estimates that about 4000 of 14,000 villages have enough) and considers measures needed to improve their supplies; suggests that not enough geologic and hydrologic data are available to support the planned drilling program.

Phiancharoen, Charoen, "Geologic Map of Northeast Thailand," from a paper presented at the 11th Pacific Congress, Aug 66, in Tokyo, in preparation, 1966.

This map represents the latest changes in geologic boundaries and interpretations. Largely the result of most recent drilling results and air-photo interpretation and mapping.

PERSONAL COMMUNICATIONS FROM:

Knud Christensen, 1966
A. Imochan, Statistics Section, Royal Irrigation Department
M. L. J. Kambhu, Apr 66
P. E. LaMoreaux, 1966 and 1967
F. R. Moormann, 1966
Charoen Phiancharoen, 1966

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13. ABSTRACT The status of water-resources investigations in Northeast Thailand is examined with particular reference to problems of civil and military water supply so as to suggest ways and means of improving existing water supply and forestalling potential water shortages in counterinsurgency operations. With 65,000 square miles and a population of roughly 10 million, NE Thailand amounts to about one-third of the entire country. Potable water is in short supply in many areas, and water distribution systems are very rare. The problem of developing more water for the civilian population is joined with the one of ensuring that sufficient water is available to counterinsurgency forces if field operations were to be undertaken. The situation is approached two ways: One aims at examination of the occurrence of water resources based on evaluation of the results of research in progress by a number of agencies. The second approach involves the preparation of scenarios to illustrate the nature of real planning problems and constraints as they might arise through three possible successive stages in insurgency in NE Thailand. Potential responsive counterinsurgency activity is suggested, including deployments of the Royal Thai Army, to set forth the problems of operations and logistics. The Royal Thai Army Engineer Combat Battalions do not have as much water-purification equipment in their TOE as they would probably need in Phase III (highest intensity) counterinsurgency operations. In the context of civil water requirements there is a shortage of water wells and potable-water production, but the most conspicuous shortage is of the application of techniques for exploiting existing water resources. The current haphazard exploitation of shallow ground-water resources is neglectful of their potential. There is no need for local people to be deprived of water because of a military requirement; sufficient availability occurs in places accessible to engineer forces. The Royal Thai Army, moreover, represents a significant source of potential manpower for carrying out an experimental civic-action program of village-level assistance in exploitation of shallow ground-water resources.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
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ground water						
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Royal Thai Army						
civil action						
deployment scenario						
TOE						
water requirements						
soils						
surface water						
vegetation						
water resources						
water supply						